CALIFORNIA BEACH RESTORATION STUDY

January 2002

Department of Boating and Waterways and State Coastal Conservancy

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Please cite this report as follows:

California Department of Boating and Waterways and State Coastal Conservancy, 2002. *California Beach Restoration Study*. Sacramento, California.

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

- ☞ *Visitors to California beaches spent over $61 billion in 2001, of which approximately 36% was spent by out-of-state visitors. California's beaches generate over $15 billion annually in tax revenue.*

- ☞ *To protect and restore this economic resource, the Department of Boating and Waterways has estimated that the State of California needs to invest $120 million in one-time beach nourishment costs and $27 million in annual beach maintenance costs. Through cost-sharing partnerships with the U.S. Army Corps of Engineers, federal funding for these shoreline projects could reduce the state's burden to $42 million (65% reduction) and $13.5 million (50% reduction) for restoration and maintenance costs, respectively.*

- ☞ *70-90% of beach sand is estimated to be delivered to California's beaches by rivers, but coastal dams prevent over one quarter of the average annual volume of sand supplied by streams from reaching the beaches. Removing dams or bypassing sediment around dams could significantly reduce the sediment deficit along much of California's coastline.*

The Public Beach Restoration Program (Program), created in 1999 by Assembly Bill 64 (Public Beach Restoration Act; Harbors and Navigation Code, sections 69.5-69.9), provided $10 million for grants to be administered by the California Department of Boating and Waterways (DBW) in fiscal year 2000-01. This appropriation was substantially higher than the annual funding for beach-related projects in prior years.

A motivating factor behind the creation of the Program was the continued loss of public beaches due to intense coastal and inland development during the past century. Dams and other flood control measures have decreased the natural sediment supply to the coast, while jetties and breakwaters have blocked alongshore sand movement. A series of beach erosion problems, on both local and regional scales, have been exacerbated by these activities; in some cases, sand bypassing programs have been implemented to alleviate downdrift erosion.

Beach nourishment, or replenishment, is the introduction of sand onto a beach to supplement a diminished supply of natural sediment, for the purpose of beach restoration, enhancement or maintenance. Continued loss of many public beaches could be reduced substantially by beach nourishment. Limited capacity at already-narrow beaches, such as those in north San Diego County, will be further strained to meet growing demands for coastal access and recreation. Beaches made wide by past nourishment programs have begun to retreat and will continue to do so without replenishment. Narrowing beaches will lead to diminished recreational opportunities and coastal access, degraded wildlife habitats, lost tourism revenues, and increased damage from coastal storms. The Program provides a funding vehicle to support restoration, enhancement, and maintenance of this valued resource.

A key component of the Program is the promotion of both local and federal partnerships. On the local level, the DBW has partnered with regional management agencies such as SANDAG (San Diego Association of Governments) and BEACON (Beach Erosion Authority for Clean Oceans and Nourishment). Federal partnerships have been forged with the U.S. Army Corps of Engineers (Corps). The DBW is currently involved in a number of federally-sponsored shoreline projects, and is actively pursuing additional partnership opportunities with the Corps. Cost-sharing agreements with the federal government make these partnerships particularly advantageous. Currently, 65% of the cost of the initial construction phase of a project is paid by the federal government, while 35% of the cost is covered by the non-federal partners, such as the state and a local government. For subsequent maintenance phases, costs are shared on a 50/50 basis.

In addition to authorizing funds for beach nourishment projects and research, the California Public Beach Restoration Act mandates that the DBW and the State Coastal Conservancy conduct a California Beach Restoration Study. This document reports the results of that study, the primary objectives of which are:

1. Detail the activities undertaken through the Program.
2. Assess the need for continued beach nourishment projects.
3. Evaluate the effectiveness of the program in addressing that need.
4. Discuss ways to increase the natural sediment supply in order to decrease the need to nourish the state's beaches.

Activities Undertaken through the Program

Following a review of grant applications submitted by various local agencies for the 2000-2001 funding cycle, $10 million was allocated for 16 beach-related projects. These projects range from local and regional beach nourishment programs to coastal research. The majority of the program budget was used for beach nourishment projects, several of which were cost-shared with the Corps. The remaining funds in that funding cycle were used for additional studies and research into erosion control and California coastal processes (Figure A).

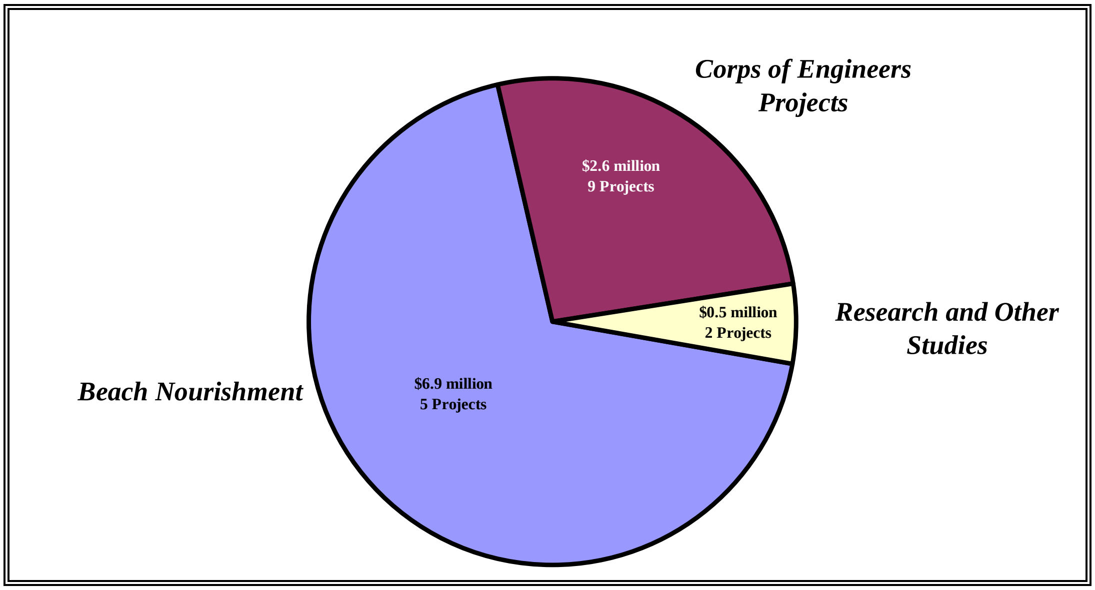

Figure A. Allocation of Public Beach Restoration Program Funds (FY 2000-01)

Need for Continued Funding of the Public Beach Restoration Program

After a century of intense development, the California shoreline is largely influenced by human activity. Alterations of the natural system have resulted from the damming of rivers, flood control, sand nourishment, and sediment-blocking structures. This is particularly true in southern California. Effective resource management is necessary to minimize beach erosion, maintain existing recreational beaches, and provide storm protection for public development.

The DBW has estimated that the State of California needs to invest $120 million in one-time beach restoration costs and $27 million in annual beach maintenance costs for 23 projects in 8 coastal counties. These projects would directly replenish 24 miles of heavily-used public beaches and collaterally benefit more than twice that length due to alongshore sand transport. Through cost-sharing partnerships with the U.S. Army Corps of Engineers, federal funding for these shoreline projects could reduce the state's costs to $42 million (65% reduction) and $13.5 million (50% reduction) for restoration and maintenance, respectively.

California beaches provide numerous benefits to the state and its residents. Some of these benefits are:

- **Recreational Opportunities:** Over two-thirds of Californians visit the beach each year. California's beaches experienced an estimated 659 million visitor-days in 2001, more than twice as many as the visitor-days at all U.S. National Parks combined. Of the state's top ten recreational destinations in 1991, three were beaches.

- **Sustainable Tourism:** Tourism is California's third-largest industry, and beaches attract many visitors to the state.

  Spending on Beach Trips: Visitors to California beaches spent over $61 billion in 2001; approximately 36% of this total was spent by out-of-state visitors.

  Tax Revenues: California's beaches generate over $15 billion annually in tax revenue (excluding social insurance). Table A provides estimates for local, state, and federal tax revenue.

Table A. Estimated Taxes Derived from Beach Spending

Government	Estimated Tax Generated	Percentage of Total Taxes Generated
Federal	$8.1 billion	53.4%
California State	$4.6 billion	30.5%
County	$1.2 billion	8.1%
City	$1.2 billion	8.1%
Total	**$15.2 billion**	100.0%

- **Coastal Access:** Nourishment can improve access to public shorelines, which are often difficult or dangerous to reach when beaches are narrow.
- **Public Health and Safety:** Beach nourishment provides numerous public health and safety benefits to residents and visitors. Wider beaches can reduce the number of sudden and dangerous bluff collapses. Increased beach widths allow public safety personnel access to respond more effectively to emergencies.
- **Wildlife Habitat:** Maintaining sandy beaches will provide habitat for many species, including several listed as threatened or endangered.
- **Protection of Public Property:** Beaches are a natural form of coastal protection; beach nourishment can reduce the need for hard structures such as revetments.

Effectiveness of the Program

Nourishment projects funded through the Public Beach Restoration Program are in the early stages of implementation, making an evaluation of their effectiveness premature. Judging from the success of prior nourishment projects, however, the current projects offer the potential for significant improvement of the state's coast.

Beach nourishment has been conducted in California for most of the past century. Many of California's most renowned beaches were created and are maintained by nourishment programs. Beaches such as Santa Monica, Venice, Newport and Mission Bay were narrow under natural conditions and incapable of supporting present-day demands for coastal access and recreation.

These beaches are now major tourist attractions, providing substantial economic and recreational benefits.

Representative historical beach nourishment efforts conducted in California include:

- **Planned Regional Beach Nourishment in Orange County:** Scheduled periodic nourishment at Surfside-Sunset Beach and nourishment with sand retention devices at Newport Beach have led to the placement of nearly 18 million cubic yards of sand on the beaches between Anaheim Bay and Newport Harbor since 1963. Results from the recent *Coast of California Storm and Tidal Waves Study – Orange County Region* indicate that the majority of this material has remained in the local sediment system (littoral cell), and beach widths in the region have increased at an average rate exceeding 4 feet per year.

- **Opportunistic Nourishment in Santa Monica Bay:** Since the 1930's, over 31 million cubic yards of sand have been placed on the Santa Monica Bay beaches, most of which (over 90%) became available from construction and dredging activities. The cumulative effect of these independent projects was the creation of wide, sandy beaches in an area that was once characterized by naturally narrow beaches.

Increasing Natural Sediment Supply

While beach nourishment is one way to increase the volume of sand on California's beaches, it is important also to consider increasing the natural supply of sediment to the shoreline. The primary source of natural sediment supply to beaches is discharge from rivers and streams. Bluff erosion is also a source of beach sand along much of the coast. Human activities have significantly affected both of these sand sources through the construction of dams, debris basins, hard channelization of stream beds, and seawalls and revetments along coastal bluffs.

In order to discuss ways to increase natural sediment supply to the coast, it is necessary to quantify the sediment volumes provided through each supply process and to assess the impact of human activities on this system.

Fluvial Sediment Supply and Reduction

- Rivers are estimated to provide 70 to 90% of the beach-size material to the coast.

- Over 480 major dams (under the jurisdiction of the Department of Water Resources' Division of Safety of Dams) have been built in California's coastal watersheds (excluding areas draining to San Francisco Bay).

- Coastal dams, built primarily for water supply, irrigation, and flood control, impact 38% (over 16,000 mi^2) of the state's coastal watershed area and impound 26% of the average annual beach-size sediment provided by streams.

- Southern California, from Point Conception to San Diego, is the region most highly affected by dams, with six of seven major littoral cells receiving two-thirds or less of the historical fluvial sediment supply.

- In Southern California each year, more than 1.5 million cubic yards of sand-size material are impounded behind dams and within debris basins. If sand were removed from behind just twelve dams, identified in this report, then the increase in local sand budgets would be substantial. If sand were bypassed around these dams at the same rate as long-term average sand deposition in the reservoirs, then bypassing could offset 40% of the sediment deficit in these Southern California littoral cells.

- In the Santa Barbara littoral cell, dam construction has reduced the volume of sediment added by streams by 41%; in the Oceanside littoral cell, dam construction has reduced the fluvial contribution by 54%.

- Long-term beach loss can be expected without management of sediment in fluvial systems.

Bluff Sediment Supply and Reduction

- The great majority of the coast of California consists of actively eroding sea cliffs. Specifically, 13% of the coastline is high-relief, steep mountains that contribute a negligible amount of sand to the littoral budget, and 59% of the coastline is low-relief (less than 300 ft) wave-cut bluffs or terraces that, when eroded, will produce a greater percent of sand-sized material than the high-relief, mountainous shoreline.

- Approximately 102 miles of the state's coastline (10%) are presently armored; 58 miles (57%) of this armor lines coastal lowlands and dunes while the remaining 44 miles (43%) of armor protect sea cliffs.

- Results of an analysis of sediment contributions from bluff erosion in two different coastal areas highlight the importance of considering solutions to beach erosion on a regional, rather than statewide, basis. In the Oceanside littoral cell, cliff and bluff erosion historically contributed 11% of the littoral budget. Armoring the cliffs of the cell has reduced the sand contribution by 18%. In contrast, bluff erosion historically contributed only 0.4% of the natural sediment budget in the Santa Barbara littoral cell; in this cell, efforts to increase natural sediment supply should focus on fluvial sediment sources rather than bluff erosion.

Recommendations

- ***Continue Investing in Beaches:*** Past beach nourishment experience in California has shown that continued funding for sand is justified by the economic benefits from tourism and beach recreation associated with wide sandy beaches (including $4.6 billion in tax revenue for the state). California should continue funding the Public Beach Restoration Program and invest in opportunistic beach replenishment.

- ***Plan Regionally:*** The California coastal environment is diverse. As a result, beach nourishment and sediment supply improvement concepts applied to one region may not be appropriate for another. Potential projects should be evaluated on a regional basis to identify the most effective solutions. The California Coastal Sediment Management Master Plan, funded through the Resources Agency, will be instrumental in enabling regional planning of sediment-related projects. As part of the Master Plan, many of the studies this report has identified as necessary to attain the goals of replenishing beaches and increasing natural sediment supply to the coast will be initiated. Identified studies include:

    - *Analysis of Sediment Reduction***:** A detailed study should be performed of historic beach widths and volumes to determine the extent to which any systematic reduction in beach width has taken place, and if so, how this reduction relates spatially and temporally to the reduction in natural sediment supply.

    - *Analysis of Environmental Impacts:* Environmental limits on sediment removal from individual reservoirs and debris basins should be investigated; these explorations should include grain size analysis to assess the size distributions of impounded sediments, identification of sediment transport alternatives, and assessment of impacts to estuaries due to increased fluvial sediment loads.

    - *Assessment of Impacts from Increasing Sediment Transport Rates:* Fluvial systems are in quasi-equilibrium with existing sediment loads. To understand the implications of altering these loads, the geomorphological, sedimentological, and ecological impacts of increasing sand transport rates in coastal systems should be modeled.

    - *Establishment of Data Collection Standards:* Better records of the number of channelized streams, miles of channelization in streams, volumes of sediment extracted from stream channels and debris basins, and the grain size distribution of the extracted sediments should be kept by local government agencies to identify opportunistic sand sources.

- ***Remove or Bypass Dams***: Substantial increases in sand volume to local sediment budgets, resulting in wider beaches, could be realized by removing those dams that are no longer serving any useful function, and bypassing sediment around those that are functional but impound significant volumes of sand.

- ***Promote Opportunistic Sand Nourishment:*** At a number of sites, "sand of opportunity" has been utilized as beach nourishment material with great success. However, under current guidelines, the cost and complexity of regulatory compliance often precludes the use of opportunistic material from sources such as debris basins and wetlands. The regulatory process for beach nourishment with opportunistic sand should be simplified to the maximum extent possible without compromising environmental safeguards.

- ***Monitor Projects:*** Beach nourishment projects should be monitored to accomplish the following objectives:

  - Determine if the project meets design expectations;
  - Develop an appropriate maintenance schedule;
  - Assess environmental impacts; and
  - Quantify the economic benefits of the project.

  An increased understanding of the performance of nourishment projects in California will lead to more effective solutions to beach erosion.

Citations for data presented in this Executive Summary can be found in the text of the report.

1. INTRODUCTION

The Public Beach Restoration Program (PBRP) was created in 1999 by Assembly Bill 64 (Public Beach Restoration Act; Harbors and Navigation Code §69.5–69.9). The PBRP recognizes that a legislative funding mechanism is required to provide for the sustainability and management of beaches, which play a significant economic, recreational, coastal access, public safety and environmental role for the State of California. The state budget for fiscal year 2000-2001 provided $10 million for grants administered by the California Department of Boating and Waterways, representing a nearly six-fold funding increase over previous years.

> The Public Beach Restoration Act found that:
>
> (a) The state's beaches provide California with an enriched quality of life, worldwide recognition, and unparalleled tourist opportunities for economic enhancement.
>
> (b) The state's beaches are California's most popular recreational destination with over 550 million visitors in 1995, 85 percent of whom were non-coastal residents.
>
> (c) Tourism is the third largest industry in the state; the state's beaches provide the attraction and recreational infrastructure that drives a major portion of that industry.
>
> (d) Beach-induced recreation and tourism produce over $10.6 billion in direct spending, produce $17 billion in indirect and induced spending, support over 500,000 jobs, and generate over $1.0 billion dollars in state taxes.
>
> (e) Many state beaches are in an advanced state of erosion and are disappearing because of human-induced impacts produced by inland development and watershed modifications, such as concrete channels, flood control structures, and water supply dams. The health of the state's beaches relies upon a steady flow of sand from watersheds via rivers and streams that are now greatly modified and dammed.
>
> (f) The state's beaches provide a natural habitat for many species, some of which are on the threatened or endangered species list, such as the least tern and the snowy plover.
>
> (g) Beaches provide exceptional, low-cost recreational opportunities for all socio-economic levels especially in densely populated areas that possess limited water recreation opportunities.
>
> (h) A dedicated state-funding source will greatly enhance our ability to partner and qualify for federal matching funds through the United States Army Corps of Engineers' Shore Protection Program.
>
> (i) The Public Research Institute at San Francisco State University has studied beach nourishment needs along the California coast and found a statewide need for one hundred thirty-two million dollars ($132,000,000) in one-time project costs with annualized maintenance costs of seventeen million six hundred thousand dollars ($17,600,000).

In addition to providing resources for projects and research, the Public Beach Restoration Act mandates that the Department of Boating and Waterways and the State Coastal Conservancy conduct the California Beach Restoration Study. This document meets that mandate. The study is intended to assess the success of and continuing need for the PBRP, and investigate ways to increase the volume of sand on the state's beaches through increasing the supply of sediment to the coast through natural processes rather than beach nourishment. The primary objectives of the study are as follows:

1. Detail the projects funded by the PBRP
2. Assess the need for continued beach nourishment projects
3. Evaluate the effectiveness of the PBRP in addressing that need
4. Discuss ways to increase natural sediment supply in order to decrease the need to nourish the state's beaches

The study is divided into four major parts. Part 1 is an overview of the state's beach setting (Chapter 2) and the economic benefits of California's beaches (Chapter 3). Part II focuses on beach nourishment. The basic concepts of beach nourishment are described in Chapter 4. The projects that were approved for 2000-2001 PBRP funding and future needs of the program are outlined in Chapter 5, while past projects that are similar to those approved for PBRP funding are analyzed in Chapter 6. Part III contains chapters on natural sediment supply along the coast; Chapter 7 focuses on fluvial contributions and reductions while Chapter 8 analyzes contributions from bluff erosion and reductions to those contributions due to coastal armoring. The final section of the report, Part IV, is a summary of the major conclusions and recommendations derived from the study.

2. CALIFORNIA BEACH SETTING

The California coast, composed of sandy beaches, sea cliffs, rocky headlands, and lagoons, extends 1,100 miles from Oregon to the U.S.-Mexico border. It can be divided into two distinct regions: southern and northern. The boundary occurs at Point Conception, where both the coastal alignment and the physical environment change abruptly. The northern California shoreline is fully exposed to winter storm waves generated in the North Pacific, while southern California is afforded partial shelter from these waves by Point Conception and numerous offshore islands.

South of Point Conception, the shoreline typically is backed by coastal plains and marine terraces. Long sandy beaches predominate, as in the case of Santa Monica Bay, although they may be separated by rocky headlands such as Palos Verdes.

The northern California coastline tends to be more rugged. At many locations, the mountains extend to the shoreline with only a narrow sliver of sand at their base. Prominent headlands interspersed with stretches of sea cliffs and small sandy beaches are common. Some areas, such as Big Sur, contain rocky bluffs and outcrops with relatively few beaches.

2.1 Beaches

Beaches are an invaluable social, economic, and cultural resource in southern California. Favorable weather and ocean conditions, combined with the high population density of the region, have resulted in these beaches becoming the most popular recreation destination in the state. Numerous activities are available, including swimming, surfing, boardsailing, boating, volleyball, diving, fishing, hiking, biking, camping, and sunbathing.

In their natural condition, many southern California beaches were incapable of supporting the recreational needs of the developing region. Wide, sandy beaches tended to be the exception rather than the rule, and were concentrated near river mouths or where sand was retained by sediment-blocking features such as headlands and reefs (Everts, 2000).

Today, however, broad, sandy beaches abound in southern California due to nourishment programs. Renowned sites such as Santa Monica and Venice, generally regarded as some of the finest beaches in the world, exist in their present condition only because they have received extensive sand through nourishment. These and other enhanced beaches provide numerous benefits, including increased recreational and tourism opportunities, restored wildlife habitats, improved coastal access, and greater protection against coastal storms.

Many beaches in northern California remain in a near-natural condition, largely due to the lack of intense coastal development. Exceptions do exist, however, including the highly urbanized San Francisco shoreline and the communities surrounding Monterey Bay.

The nature of coastal recreation and usage in northern California is distinctly different from that in southern California. A cooler climate and more severe wave conditions in the north limit the popularity of water sports. The coast is valued for its scenic beauty, in that it contains some of the most spectacular vistas in the country. As a result, recreation frequently involves leisurely travel along the coast for enjoyment of the rugged scenery. In addition, abundant inland recreation alternatives and a lower population density result in less beach visitation than in southern California.

2.2 Sand and the Beach Environment

The geography of the California coast effectively separates the coastline into discrete coastal compartments termed littoral cells. A littoral cell is a self-contained system that may be bounded by rocky headlands or by a submarine canyon that intercepts the sand as it moves along the coast. Sand is supplied to the beaches primarily by rivers or bluff erosion, moves within the system under the influence of waves and currents, and eventually may be lost from the littoral cell. Typically, there is little sediment exchange between adjacent cells.

Most California beaches, particularly those valued for recreation, are comprised of sand. Their width is dependent on many factors, including the sand supply, the wave climate, the presence or absence of sediment-retaining features, and the configuration of the sea bottom. Wide beaches tend to exist where the sediment supply is plentiful or the sand is trapped by headlands or reefs. Conversely, a beach may be narrow or non-existent if deprived of sediment or if the sea bottom is very steep.

Up to 90% of the natural sand supply for California beaches is provided by rivers and streams. Most of this material is transported to the coast during winter storms. Eroding sea cliffs and bluffs provide a secondary source of sediment (DNOD, 1977; Part III, this report).

Once it arrives at the coast, the sand is distributed by waves and currents. Adjacent beaches are replenished as the flow of sand proceeds alongshore. Notwithstanding seasonal and local variations, the predominant direction of alongshore sand movement in California is north-to-south.

Sand also moves onshore and offshore in what is largely a seasonal process. During winter storms, sediment from the dry beach often is transported seaward and deposited in nearshore sand bars. When summer arrives, milder wave conditions tend to move the sediment back to the dry beach. As a result, the beach may become narrow in winter and then recover much or all of its original width in summer.

Sediment eventually may be lost from the littoral system by transport into one or more sinks. The most common sinks along the California coast are submarine canyons, harbor entrances, lagoon inlets, and coastal dunes. Sand also may be lost offshore, beyond the depth at which waves are capable of transporting it back to the beach.

A delicate balance exists between sediment supplies, sand transport, and sediment losses. Alterations to the system, both natural and man-made, can result in accelerated beach erosion or accretion. Natural changes in sediment supply occur in response to weather conditions, with greater quantities of riverine sand delivered to the coast during floods than during dry periods. Human-induced changes can result from flood control measures, sand nourishment, and construction of sediment-blocking structures.

2.3 Impacts to the Natural Condition

After a century of intense development, the condition of the California coastline is influenced largely by human activity. This is particularly true in southern California, where urbanization has progressed most rapidly. Continued human involvement is necessary to maintain existing recreational beaches, mitigate erosion, and provide storm protection for public development.

Significant changes in the natural condition of the shoreline began in the early 1900's. Human intervention commenced with the channelization and damming of rivers to limit inland flood damage and create reservoirs for water supply and irrigation, and the construction of coastal harbors to support commerce and recreation. The flood control measures reduced the amount of sand reaching the coast, while the harbor structures effectively obstructed alongshore sand movement. The result was a series of erosion problems, on both local and regional scales.

Flood control measures are particularly widespread in southern California and include dams, debris basins, and river channelization. Consequently, many of the region's beaches have been impacted by a reduced contribution of sediment. The most drastic sand deficit exists along the Orange County shoreline, where the natural sediment supply has declined by as much as 85% (Flick, 1993).

Coastal erosion problems have arisen not only from dams, debris basins and stream channels, but also from the tendency of coastal harbors to restrict alongshore sediment transport. As with flood control measures, harbor-related problems tend to be more pronounced in southern California. The problems often are recurring and must be addressed on a regular basis. Where harbors have led to erosion problems, sand bypassing or other nourishment programs have been implemented to restore eroded downcoast beaches.

Not all coastal development has produced negative impacts. Several of the region's most popular beaches were created and are sustained by sand nourishment projects and retention devices. The world-famous shoreline of Santa Monica Bay, for example, was produced by numerous beach nourishment projects, most conducted prior to 1970 (Leidersdorf et al., 1993). Similarly, the predominantly wide, sandy beaches of northern Orange County are largely a product of regional sand replenishment and beach compartmentalization projects. These famous shorelines, once starved for sand, now attract millions of visitors each year, adding billions of dollars to the state economy.

2.4 Natural Sediment Supply

California's beaches depend upon periodic nourishment of sand-size sediment from rivers and streams, gully and terrace erosion, and coastal bluff erosion. Budgets of littoral sediment from natural sources have estimated that rivers and streams supply, on average, 70 to 90% of the beach sand in California (Bowen and Inman, 1966; Best and Griggs, 1991), with the remaining 10 to 30% of sand provided by gully, terrace, and bluff erosion.

California's coastal watersheds are of two general types: (1) the steep, erodible, conifer-forested Coast Range basins north of Monterey Bay, which are characterized by high seasonal rainfall and perennial streams, and (2) the more arid basins of central and southern California, which often drain chaparral- or grassland-covered headwaters, with broad alluvial valleys in their lower reaches. California's coastal rivers have exceptionally high sediment loads due to the steep topography, the geologically-young and tectonically-active terrain, and, in central and southern California, the relatively sparse vegetative cover. In both northern and southern California, almost all sediment is delivered to the coast during winter storms between November and March. This seasonal pattern of rainfall and sediment delivery is heightened by infrequent, exceptionally wet years when large floods flush enormous quantities of sediment out of coastal watersheds (Inman and Jenkins, 1999). When sediment is delivered to the coast, the fine silts and clays are quickly moved offshore by wind- and wave-generated currents, while the sands and gravels are deposited at the river mouth as beach or delta deposits that are available for transport along the coast by longshore currents.

The coastline of California can be broken down into three very general categories: 1) high relief, steep cliffs; 2) bluffs eroded into lower relief (less than 300 ft [100 m] in height) marine terraces; and 3) coastal lowlands or plains. Erosion of California's cliffed coastline provides sediment to the coastal zone. The amount of sand-size material supplied to the coast through cliff erosion depends on both the type of rock and terrace material that make up the cliff and the rate of cliff erosion. The high-relief, steep cliffs of California are composed predominantly of resistant rocks and generally are not a major contributor of sand-size material to the littoral budget. The lower-relief marine terraces, however, play a more important role in terms of sand contribution. Marine terraces are comprised primarily of marine sedimentary rocks, capped by terrace deposits which, when eroded, will produce a greater percent of sand-size material than the high-relief, steep bedrock cliffs.

The two main natural sediment sources for California's beaches—coastal streams and bluffs—have been impacted by development in coastal watersheds and along the coast. Dams and debris basins, in-stream sand and gravel extraction operations, and stream bank and bed channelization have reduced fluvial sand supplies, particularly in highly urbanized southern California. Similarly, coastal armor, built to protect bluff-top coastal structures, has halted bluff erosion, preventing the sand portion of the bluff from reaching the beach.

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3. THE BENEFITS OF CALIFORNIA'S BEACHES

3.1 Overview

This chapter discusses the benefits of beaches and beach nourishment to the State of California, the nation and local communities. The first part provides an overview of the recreational needs of California and the role beaches play in fulfilling that need. The second section discusses the fiscal impact of beaches for the state, local communities and the nation. Part three is a discussion of the recreational value of beach nourishment projects to residents of California as well as to visitors from other states and countries. Part four presents a case study of overcrowding at north San Diego County's beaches. Part five discusses environmental and public safety benefits of beaches.

California's beaches provide a wide range of economic, environmental and public safety benefits to the state's citizens, visitors and some wildlife species. As this chapter demonstrates, the recreational needs of Californians are growing rapidly and beach visits provide an important recreational outlet. Almost two-thirds of California's residents visit one of the state's beaches at least once a year. These visits generate $61 billion in spending and $15 billion in total tax receipts, of which $4.6 billion go directly to the State of California. Unfortunately, California's beaches are eroding, largely due to human influence, degrading and reducing available recreational opportunities while the population continues to grow more rapidly than it does in the rest of the nation. A case study of north San Diego County (Section 3.5) concludes that a significant loss of recreational opportunity will occur if beaches are not sustained at their historical widths. Our analysis indicates that north San Diego County alone will lose 49 million visitors over the next ten years if it fails to maintain historical beach widths. This loss will severely limit the opportunities for outdoor recreation and further stress a system that is already operating at capacity during peak season. There are few comparable alternatives to the beach in north San Diego County, where existing freshwater recreational facilities and parks are already crowded (Dirksen et al., 1999). The loss in tax revenue from diminished tourism substantially exceeds the cost of maintaining these beaches.

3.2 Beach Recreation and Tourism in California

3.2.1 The Need for Recreation

The long-term benefits of outdoor recreation have been well documented by the medical community and by psychologists.[1] Beaches provide an important venue for outdoor recreation for Californians as well as for many people who reside outside of California. Table 3.1 presents estimates of participation in various outdoor activities by residents of California and for all U.S. residents.[2] Nationally, 24.8%, almost one in four, of residents of the U.S. attend beaches at least once a year, compared to only 15.7% who say they attend at least one picnic, 13.1% who attend zoos, and 5.1% who go bird watching. This result is quite striking when one considers that many Americans have limited access to beaches. According to a survey completed for the State of California in 1997, 63.8% of Californians go to the beach at least once a year (King and Potepan, 1997). An earlier study by the State Department of Parks and Recreation indicated a similar level of attendance.[3]

Table 3.1 How Many People Go to the Beach?

Percentage of Californians who go to the beach every year	**63.8**
Percentage of Americans who go to the beach every year	**24.8**
Percentage of Americans who go to picnics every year	**15.7**
Percentage of Americans who go bird watching every year	**5.1**
Percentage of Americans who go to the zoo every year	**13.6**

Source: King and Potepan (1997); U.S. Dept. of Commerce (2001)

Nationally, spending on recreation is increasing as well. Table 3.2 presents the share of income that Americans devote to recreation over time. As one can see, recreation has become an increasingly important focus of spending for the average American. Economists believe that the increase is largely due to the "income effect"—as Americans become wealthier and as food, shelter and other necessities become more secure, people have more resources to devote to activities they enjoy. Indeed, if one accounts for the increase in real income, **Americans spend over ten times as much on recreation in inflation-adjusted dollars today as they did in 1919**.

[1] See, for example: Marano, H., 1999; Bishop, 1998; and American Recreation Coalition, 1999.
[2] Unfortunately, the census does not keep data on all forms of outdoor recreation.
[3] See California Department of Parks and Recreation website.

Table 3.2 How Much Do People Spend on Recreation?

Year	Percentage of Household Budget Devoted to Recreation
1919	3.60%
1935	4.00%
1950	5.30%
1972	6.70%
1991	8.00%
2000	8.50%

Source: Costa, 1997, 1999

3.2.2 Population Projections for California

In addition to the increased demand for recreation due to higher income levels, California's population is expected to grow substantially over the next 20 years. The California Department of Finance's Demographic Division has detailed projections of population at the state and county level. As presented in Table 3.3, the Finance Department projects California's population will grow by 32.8% over the next twenty years. The rate of increase is even larger in some areas. For example, San Diego County is projected to grow by 39.3%, and other southern California counties are projected to grow by over 50%.

Table 3.3 Population Projections (in millions)

Year	California	Los Angeles	San Diego
2000	34.5	9.7	2.8
2005	37.5	10.2	3.1
2010	40.3	10.6	3.4
2020	45.8	11.6	3.9
% Increase 2000-2020	**32.8%**	**19.6%**	**39.3%**

Source: California Dept. of Finance, 1998

3.2.3 Attendance at California's Beaches

Given that over two-thirds of Californians visit the beach at least once a year and millions go regularly, it should not be surprising that the attendance at California's beaches is enormous. Unfortunately, attendance estimates are imperfect and sometimes not available. Most local beaches with lifeguards and/or parking keep attendance records based on lifeguard counts or parking figures. A number of beaches in the state, including many Los Angeles beaches, Huntington Beach and the larger San Diego County beaches, have attendance of several million visitors a year per beach. The largest of these beaches have attendance of 6-8 million visitors per year. Some of these estimates will be presented later in the report.

Table 3.4 California Beach User Origin Profile

Location	Percentage from Other US States	Percentage from Other Countries	Total Percentage of Visitors from Out of State
Seal Beach- Path	22.2	5.1	27.3
Seal Beach-East	10.5	10.8	21.3
Seal Beach-Cab	8.4	17.1	25.5
Ventura Point	5.9	6.7	12.6
Ventura State Beach	3.8	2.8	6.6
Ventura City Beach	1.9	4.1	6.0
Ventura Harbor	2.6	-	2.6
Seal Beach Pier	20.6	23.3	43.9
Carpenteria	48.3	1.0	49.4
Ventura Boardwalk	11.7	2.7	14.5
Laguna Main	70.0	6.9	76.9
Corona	17.4	0.5	17.9
Huntington State Beach	5.3	0.5	5.8
Huntington City Beach	7.5	4.2	11.7
Seal Pier	12.0	3.4	15.4
Seal Beach	12.6	1.5	14.1
Venice Beach	10.1	13.3	23.4
Venice Walk	17.7	10.4	28.1
Mission Beach Boardwalk	49.0	6.6	55.6
Mission Beach	48.4	4.2	52.6
La Jolla Shores	22.8	-	22.8
Carlsbad	40.7	-	40.7
Coronado	53.1	6.0	59.1
Silver Strand	16.4	4.2	20.6
Imperial Beach	-	21.5	21.5
San Clemente	24.6	-	24.6
Manhattan	25.2	10.9	36.1
Venice Beach	24.3	27.6	52.9
Venice Boardwalk	25.3	28.6	53.9
Santa Monica	18.0	40.5	58.5
Pismo	7.8	5.1	12.9
La Selva	3.7	0.7	4.4
Santa Cruz	15.3	3.1	18.4
Carmel	8.5	6.2	14.7
Total			28.4

Local beach communities do not track attendance numbers by residency. While many lifeguard stations keep track of the residency of beachgoers requiring medical attention, these figures do not provide a random sample of visitors, since a disproportionately high number of those needing assistance are surfers, who tend to be local. The best way to get an estimate of attendance by out-of-state and out-of-country visitors is a random sample of beachgoers.

Several surveys have been conducted by the California Department of Boating and Waterways. Table 3.4 above presents the results of the most comprehensive survey of beach goers, mostly in southern California. The salient details from the survey are:

- The survey indicates that 28.4% of visitors were from out of state, with roughly one-third of these from other countries.
- Adjusting for the fact that smaller beaches have fewer non-local visitors, we estimate that between 20% and 25% of all visitors to California's beaches reside out of state, with one-third of these from out of the country.[4]
- Beaches with local lodging and other facilities attract more foreign and out-of-state visitors.
- In general, San Diego beaches attract a higher percentage of out-of-state visitors than beaches in other counties in California, largely due to the proximity to Arizona and New Mexico.

Estimates of total beach attendance by state residents were obtained through a telephone survey conducted in 1995 for the California Department of Boating and Waterways, in which 600 residents across the state were randomly sampled (King and Potepan, 1997). According to the survey, California's beaches experienced 566.8 million attendance days in 1995, 15% of which were by out-of-state visitors[5]. Please note that these attendance figures include people attending boardwalks, restaurants, piers and other recreational sites with attached beaches. If one looks strictly at those on the beach, the number will be lower, but still several hundred million visitor days, an enormous number, far larger than other comparable forms of outdoor recreation in California. By comparison, all U.S. National parks experienced 286 million visitor days last year and Yosemite experienced 3.4 million visitor days (American Recreation Coalition, 1999).

Table 3.5 presents the results of the 1995 survey, updated for 2001. We have made two revisions to update the data. First, we have increased the number of visits in proportion to the population increase in California and the rest of the United States. Second, we have adjusted the original estimate of the total proportion of out-of-state visitors from 15% to 20% given the results of survey data collected since 1995, which indicate a higher value is warranted. As we mention above, the true proportion of out-of-state visitors is probably greater than 20%, so our estimate is conservative. Updating these figures, we estimate that California experienced 659.2 million beach attendance days in 2001.

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[4] For this report we have used the more conservative estimate, 20%.
[5] A beach attendance day, or visitor day, is defined as a trip to the beach to recreate on any given day.

Table 3.5 Estimated Total Attendance at California Beaches including Piers and Boardwalks 1995-2001

Item	Est. 1995 Attendance (millions)	Population in 2001 compared to 1995	Est. 2001 Attendance (millions)
Day Trips	345.8	109%	378.5
CA Overnight trips	136.0	109%	148.9
Out of State Overnight	85.0	106%	89.7
Corrected Out of State			42.2
Total	**566.8**		**659.2**

3.3 The Fiscal Impact of Beach Recreation and Tourism in California

3.3.1 Spending on Beach Trips

Given the magnitude of attendance and spending on recreation, it should not be surprising that the economic and fiscal impact of beach recreation and tourism in the State of California is significant. This section presents an overview of beach spending followed by estimates of the local, state and federal tax revenues generated by this spending.

Table 3.6 updates an earlier study and provides an estimate of spending per household and per individual on day trips and overnight trips to the beach by Californians. As one can see, day visitors spent, on average, $102.61 last year per household, or $34.56 per person, per day on fuel, food (including restaurants), rentals, sporting goods and other items. As one would expect, spending on overnight trips is considerably higher, reflecting not only higher food costs and hotel bills, but also the fact that overnight visitors tend to come from farther away and, since they are likely to be on vacation or a weekend trip, are likely to spend more money. Including all expenses, in 2001, we estimate that households spent an average of $505 per day, or $170 per person per day on overnight beach trips in the last year.

Table 3.6 Estimated Spending per Household on Trips to the Beach--per Trip

Category	2001 Overnight Spending per Trip per Household	2001 Day Spending per Trip per Household
Gas & Auto	$ 62.96	$ 19.72
Beach Related Lodging	$ 201.20	
Parking & Entrance Fees	$ 6.08	$ 6.08
Food & Drinks from stores	$ 70.54	$ 26.89
Restaurants	$ 111.33	$ 32.90
Equip Rental	$ 26.93	$ 7.48
Beach Sporting Goods	$ 6.92	$ 6.95
Incidentals	$ 19.38	$ 8.67
Subtotal Subject to Fuel Tax	$ 56.66	$ 17.75
Subtotal Subject to State Sales Tax	$ 227.52	$ 75.72
TOTAL	$ 505.34	$ 202.16
Mean Expenditure per Person 2001	**$ 170.21**	**$ 68.13**

To account for the total spending at beaches, one also must account for out-of-state spending. While reliable data on the precise amount spent by people from out of state are scanty, several surveys indicate that visitors from out of state spend, on average, about the same as visitors on overnight visits within the state,[6] and we will assume that out-of-state visitors spend the same amount per visitor per day. Table 3.7 presents the overall estimate of total beach spending in the state. We estimate that total spending on beach tourism was just over $61 billion in 2001. Of this total, $22.4 billion, or 36%, were spent by visitors and tourists from out of state (including foreign visitors).

Table 3.7 Estimated Total State Spending on Beach Tourism by Type of Trip 2001

Type of Trip	Number of Days (millions)	Avg. Spending per day	Total Spending ($ millions)
Day Trips	378.53	$ 35.95	$ 13,608.23
Overnight Trips-in State	148.85	$ 170.21	$ 25,335.97
Overnight Trips-out of State	131.85	$ 170.21	$ 22,441.48
Total	659.23		$ 61,385.69

[6] For example, see King, 1999. *The Fiscal Impact of Beaches in California*

3.3.2 The Fiscal Impact for the State of California

Given the estimates of spending by California residents as well as out-of-state residents, it is possible to provide reasonable estimates of the total taxes derived from this spending. Tables 3.8 and 3.9 present the estimated tax paid to the State of California by California residents and by out-of-state visitors respectively. The table breaks down these estimates into spending on day trips and spending on overnight trips, and into taxes generated by the Personal Income Tax, state proceeds from sales taxes, state taxes on fuel, and other state taxes. Where possible, we have used applicable tax rates applied directly to the relevant spending categories. For example, our spending survey estimates divide spending into categories that are subject to sales taxes and categories (food purchased at grocery and convenience stores) that are not subject to sales tax. In other cases, we have used average rates of taxes per dollar obtained from the California Statistical Abstract (CA Dept. of Finance, 2000).

Table 3.8 Estimated Tax Derived from Beach Spending by State Residents

Tax	Estimated on:	Rate	Day Trips	Overnight Trips	Total
CA Personal Income	Income	3.0%	$ 410,968,627	$ 765,146,263	$1,176,114,890
State Sales Tax	Non-Exempt Sales	4.8%	$ 458,937,647	$ 541,556,337	$1,000,493,984
State Fuel Tax	$0.18 per gallon	9.0%	$ 208,205,960	$ 255,386,567	$ 463,592,527
Other State Taxes	Income	1.7%	$ 231,339,955	$ 430,711,472	$ 662,051,428
Total			$1,309,452,189	$1,992,800,640	$3,302,252,829

Table 3.9 Estimated Tax Derived from Beach Spending by Out-of-State Visitors

Tax	Estimated on:	Rate	Overnight Trips
Personal Income	Income	3.0%	$508,299,607
State Sales Tax	Non-Exempt Sales	4.8%	$359,765,036
State Fuel Tax	$0.18 per gallon	9.0%	$169,657,617
Other State Taxes	Income	1.7%	$286,128,918
Total			$1,323,851,180

Finally, Table 3.10 presents the estimate of total state tax derived from both state residents and out-of state visitors. Overall, we estimate that beach spending generates $4.6 billion in state tax revenues.

Table 3.10 Taxes From Beach Spending by Residents and Out-of-State Visitors

Est. State Tax from Out-of-State Visitors	$1,323,851,180
Est. Tax paid by Residents	$3,302,252,829
Total Tax Derived from Beach Spending	**$4,626,104,009**

3.3.3 The Fiscal Impact for the Federal Government and Local Government

One common issue with regard to investment in beach nourishment is the benefits derived from beaches by various governments, from local city government to the state and federal government. The tables below present estimates of federal and local taxes generated by beach spending and comparisons of these estimates with our estimates of state taxes presented above. For these calculations, we have relied on average taxation levels per dollar, collected from the State of California's *Statistical Abstract* (CA Dept. of Finance, 2000) and from averages calculated for the federal government by the U.S. Office of Management and Budget (Economic Report of the President, 2001). The estimates of total federal taxes generated are presented in Table 3.11, broken down by category. We have also provided a subtotal for federal taxes excluding taxes on social insurance (the Social Security and Medicare taxes). **Overall, we estimate that spending on beach recreation and tourism in the State of California generates $13.6 billion dollars in federal taxes; excluding social insurance, our estimate is $8.1 billion**.

Table 3.11 Estimated Federal Tax Revenues Derived from Beach Spending in California

Tax	Total Spending in California	Avg. % of Total U.S. Spending	Est. Tax Revenues
Federal Income Tax	$ 61,385,685,438	10.4%	$ 6,384,111,286
Federal Corporate Taxes	$ 61,385,685,438	2.1%	$ 1,289,099,394
Federal Excise Taxes	$ 61,385,685,438	0.7%	$ 429,699,798
Subtotal Excluding Social Insurance	**$ 61,385,685,438**	**13.2%**	**$ 8,102,910,478**
Other	$ 61,385,685,438	9.0%	$ 5,524,711,689
Total Federal Tax Receipts		**22.2%**	**$13,627,622,167**

Finally, Tables 3.12 and 3.13 present our estimate for local tax revenue generated compared to state and federal revenue. Our estimates for local revenue are based on averages for the state and should be considered only an approximation, but they do provide an indication of how tax revenues are distributed. If one includes federal programs for social insurance, then spending on beach recreation and tourism in the state of California generates $20.7 billion in revenues, of which 65.8% goes to the federal government, 22.4% goes to the state and only 5.9% goes to the local and county governments. Excluding social insurance, the estimates are: 53.4%, 30.5%, and 8.1%. In sum, the federal government collects the largest share of taxes. The reason for this result is twofold: (1) the federal share of taxes from dollars spent in the state of California is significantly greater than the state's share or the local share; (2) a portion (estimated as 25%) of spending by out-of-state visitors occurs outside of California and hence is not collected by the state, but this spending *does* generate tax revenue for the federal government.

Table 3.12 Estimated Taxes Derived from Beach Spending for Federal, California State, County and City Governments Excluding Social Insurance

Government	Estimated Tax Generated	Percentage of Total Taxes Generated
Federal (Excluding Social Insurance)	$8,102,910,477.86	53.4%
California State	$4,626,104,009.45	30.5%
County	$1,227,713,708.77	8.1%
City	$1,227,713,708.77	8.1%
Total	**$15,184,441,904.85**	100.0%

Table 3.13 Estimated Taxes Derived from Beach Spending for Federal, California State, County and City Governments Including Social Insurance

Government	Estimated Tax Generated	Percentage of Total Taxes Generated
Federal	$13,627,622,167	65.8%
California State	$ 4,626,104,009	22.3%
County	$ 1,227,713,708	5.9%
City	$ 1,227,713,708	5.9%
Total	$20,709,153,594	100.0%

Although the tables above present estimates for taxes generated by city and county governments, the city and county where the tourists visit a California beach may not collect these revenues. In one recent study of Huntington Beach, it was estimated that 50% of all spending on beach-related activities occurred away from the City of Huntington Beach (King, 1999a). Given that the proportion of out-of-state visitors at Huntington Beach is lower than at many other beaches, we believe that this estimate is not excessively high, and may even be an underestimate. If we apply this 50% figure, then **only about 3% of all tax revenue generated by beach spending reaches city governments,** which provide police, lifeguard and other services for beach visitors as well as maintain beach infrastructure such as restrooms, parking lots, lifeguard structures and beach maintenance vehicles.

3.3.4 Valuing the Benefits of Beach Nourishment Projects

During the spring of 2000, the Department of Boating and Waterways commissioned a study of the economic benefits of specific beach projects across the state. The projects included repairs of existing protection structures, nourishment projects, and the creation of barrier structures designed to impede sand loss and reduce beach erosion. For each individual site, a survey sheet was created and individuals likely to be familiar with the site, such as state and municipal officials, park rangers, academics and consultants who had conducted recent surveys, were contacted by telephone or (in a few cases) on-site interviews.

The survey sheet was designed to collect: (1) attendance records and the methodology by which these estimates were obtained for the last several years; (2) the percentage of visitors who were local, on day trips, or from out of town staying overnight in local hotels or campgrounds; (3) the recreational activities and amenities available and a breakdown of the proportion of people engaged in these activities; (4) an assessment of the coastal protection issue (usually erosion) and an estimate of the rate of erosion and recent damages to state and municipal property; and (5) an assessment of public infrastructure (e.g., parking lots, bathrooms, lifeguard stations, stairways, public roads and sewer lines) threatened by erosion and the likelihood that these facilities would be damaged by various storm events.

<u>Economic Value</u>

Public properties, like beaches, are entities to which it is typically difficult to assign economic values. Unlike private property, most public property never changes hands and therefore has no market value. In addition, beaches, parks and wildlife refuges typically have open access (though a small parking fee may be assessed) so that one has difficulty determining the precise benefit to society of these goods. The study was limited in that it only considered direct recreational value.[7]

In assessing the recreational value of each site, the standard methodology employed is to assess a dollar value for each visit. This technique is employed by all branches of the federal government involved in valuing recreational activity, including the U.S. Army Corps of Engineers, the National Park Service, and the National Oceanic and Atmospheric Administration (NOAA), and is considered a standard tool for economists wishing to assess the value of a recreational site.

[7] For beaches, parks and the other recreational sites, recreational value comprises most, but not all, of the value. Thus, it should be understood that the benefit estimates were probably too low and that the total benefits, which include non-use benefits, are somewhat higher. At some sites, where threatened wildlife such as the snowy plover exist, we have mentioned this, but we have not attempted to assess an economic value since doing so would require substantially more time and resources than were available for this project. Similarly, many citizens of California may wish to preserve beaches even if they never visit beaches themselves. It should also be mentioned that beaches give direct values to casual passers-by who may not visit the beach but visit nearby sites, or even just drive by. These values are also likely to be significant. Again, our estimates should be seen as lower bounds.

For each site, a value per visitor was developed. The value varies depending upon a number of factors: the type of activity, the quality of the site and the level of amenities, and the level of crowding at the site. Numerous studies of this type have been conducted. The most credible values were derived for the American Trader Case, which involved litigation from an oil spill off of Huntington Beach.[8] Correcting for inflation, the value of a beach day was estimated at $14.11 (2000 dollars). Please note that this value is conservative; it is actually slightly lower than the figure used by the Department of the Interior ($14.57 in 2000 dollars) and significantly lower than the value determined by some other studies conducted by professional economists.[9] Please note that this value also takes into account the crowded nature of many Southern California beaches.

Using the $14.11 value as a baseline, we adjusted the values for each beach. The adjustment was made using a standard methodology employed by the Department of the Interior, NOAA and most state and local agencies.[10]

One must also adjust these beach values for the types of activities available at a site. Surfing, windsurfing and camping are all considered higher-value activities, because of the higher expense involved, and the scarcity of available sites for these activities. Surfing received a slightly higher value; wind surfing received a bit higher value, and camping received the highest value. The National Park Service estimates the value of camping overnight in a National Park at $40 per person per day. In all cases, we used a lower number than $40, adjusted for the quality of the site. Note also that we used much lower values per visitor for casual hiking and jogging.

Other Issues

For some sites, the loss of infrastructure is an issue. We relied primarily on estimates from local officials and engineering studies from the Army Corps of Engineers or local engineering-consulting firms for these values.

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[8] See "The American trader Oil Spill: A View from the Beaches," by Chapman, Haneman, and Ruud, 1998.

[9] See, for example, "Recreational Use Value for Three Southern California Beaches," by Leeworthy and Wiley (1993) NOAA Strategic Environmental Assessments Division.

[10] The National Parks Service, in "Benefit Estimation," describes this "benefits transfer" technique in more detail. This "benefits transfer" technique is widely used and accepted by resource economists. Using this technique, one ranks each site on a scale of 1-5 or 1-10 for various levels of amenities, such desirability and aesthetics of the location, number of recreational facilities available, level of overcrowding, etc. In most cases in this report, the key factors were the width and quality of the beach, accessibility of the beach, and other recreational facilities available. Note that the $14.11 value used as a base is applied to beaches that are often crowded. It is difficult to find a beach in California with a high level of amenities that is not crowded on weekends. If such a beach did exist, it would likely command a higher valuation. In a number of cases where the beach had already eroded or where the amenity level was low, we assigned substantially lower values, from $4 to $10 a day per visitor. We also paid attention to the number of out-of-town visitors on day trips or overnight stays, who almost always place a significantly higher value on their beach trips than do locals.

Some of the values used and data obtained are from studies that are a few years old. To value these numbers properly, one must adjust for changes in the cost of living. The most widely used method for cost-of-living adjustments uses the U.S. Bureau of Labor Statistics (BLS) Consumer Price Index (CPI) data. The BLS now has data for specific metropolitan regions in California going back to 1990, which we used when possible. If these data were not available or appropriate, we used the more general BLS index.[11]

The Department of Boating and Waterways asked for an assessment of the value of beach projects over a 50-year period. This sort of evaluation requires that one discount future benefits. We used a real discount rate of 3.5%.[12] In many cases, however the benefits of the project will not last for 50 years. In the case of nourishment, we have assumed that the benefits diminish rather quickly (most of it disappears within 5 years). Even with these rapid rates of diminishment, many of the projects generate sufficient benefits to justify the costs. For groins, revetments and seawalls, we assumed that the projects would need to be rebuilt at a cost equal to 50% of their initial value (in 2000 dollars) paid in 2025.

Benefit/Cost Ratios

The benefit/cost ratios are shown in Table 3.14 below. **The results clearly show that beach restoration is a good investment, even if one considers only recreational value and damages to public infrastructure.** In general, any benefit/cost ratio above 1 represents a sound investment. As on can see in the table, in some cases these ratios are quite high, with a number well over 10:1.

[11] These data can be obtained at: www.bls.gov.

[12] The appropriate discount rate must take into account several criteria: (1) the rate at which a government agency may borrow; (2) the inflation rate; and (3) the likelihood that the amenity will increase in value at a higher rate than inflation. The state of California does not regularly issue bonds, but the U.S. government now issues inflation-adjusted bonds that serve as a good proxy for the "real" interest rate appropriate for discounting. The 2001 rate for long-term bonds is 3.8%. We have adjusted this number upward to account for slightly higher state borrowing costs; we use 4% for discounting losses to public infrastructure. For unique recreational sites like beaches, we believe that this methodology seriously underestimates the future value of these resources. Numerous studies indicate that individuals value natural (and man-made) recreational facilities at much higher rates as their income rises. Economists have found that the demand for recreational activities like beach visits increases roughly twice as fast as income. Thus, if real income increases by 2%, the value of a beach visit will increase by 4%. To incorporate some of this effect, we believe that it is appropriate to use a discount rate of 3.5% for recreational activities.

Table 3.14 Shoreline Protection Survey 2000

Location	Conceptual Project	Project Cost	Net Project Benefit	Benefit/Cost Ratio
Venice Beach	Groin repair (3)	$ 2,000,000	$130,270,671.81	65.14
Leo Carrillo State Beach	Retention structure/dune construction	$ 170,000	$ 8,310,900.24	48.89
Dockweiler Beach	Groin repair (2)	$ 1,350,000	$ 42,520,220.65	31.50
Topanga Beach	Seawall	$ 630,000	$ 8,798,226.74	13.97
East Beach	Groin repair (1)	$ 1,500,000	$ 17,379,719.00	11.59
Will Rogers Beach	Groin repair (6)	$ 3,900,000	$ 43,060,455.73	11.04
Pierpont Beach	Groin repair/beach nourishment	$ 820,000	$ 13,432,299.80	16.38
Hueneme Beach	Seawall	$ 850,000	$ 12,382,432.29	14.57
El Granada	Revetment	$ 1,000,000	$ 13,843,292.42	13.84
Beach Boulevard	Repair Rock toe	$ 824,000	$ 10,328,642.06	12.53
Carpinteria State Beach	Cobble berm	$ 6,500,000	$ 44,106,263.96	6.79
Pismo Beach	Beach nourishment/ retention structure	$ 4,000,000	$ 26,059,465.66	6.51
San Buenaventura	Groin repair	$ 3,800,000	$ 14,945,698.65	3.93
Beach Accessway	Revetment	$ 50,000	$ 187,382.83	3.75
El Capitan State Beach	Beach nourishment/retention	$ 3,600,000	$ 10,301,836.33	2.86
Ashby Interchange	Revetment	$ 275,000	$ 735,491.87	2.67
The Hook	Shotcrete retention wall	$ 2,000,000	$ 4,896,221.99	2.45
Refugio State Beach	Beach nourishment/retention	$ 2,600,000	$ 5,518,840.89	2.12
Coyote Point	Beach nourishment/retention	$ 5,500,000	$ 8,579,945.00	1.56
Twin Lakes Beach	Seawall	$ 5,000,000	$ 7,632,443.97	1.53
Surfers Point	Cobble berm/retention	$ 7,700,000	$ 10,820,353.53	1.41
Carlsbad State Beach	Beach nourishment	$21,000,000	$ 28,516,254.31	1.36
Hobson	Nourishment/retention	$12,300,000	$ 12,752,134.73	1.04
La Conchita	Nourishment/ retention	$12,300,000	$ 12,608,042.81	1.03
Dan Blocker Beach	Beach nourishment/retention	$ 5,700,000	$ 5,748,354.79	1.01
Leadbetter Beach	Seawall	$ 2,360,000	$ 1,474,537.15	0.62
Isla Vista	Beach nourishment/retention	$13,700,000	$ 6,781,239.88	0.49
Cayucos Beach	Seawall	$ 820,000	$ 372,877.80	0.45
Emeryville Marina	Revetment/ promenade	$ 180,000	$ 180,000	0.28

3.4 CASE STUDY: The Economic Impact of Beach Erosion on North San Diego County

Southern California beaches are crowded in summertime, particularly beaches with adequate facilities and good highway access. During the summer of 2000, a survey of beach goers was conducted, commissioned by the California Department of Boating and Waterways. The purpose of the survey was to estimate the factors that influence an individual's decision to attend a beach in Southern California. In particular, the survey attempted to assess the influence of crowding on the decision to go to a beach. All types of visitors were surveyed, including local, in-state and out-of-state visitors. Using these estimates, we projected the benefits derived from one specific beach nourishment project in north San Diego County. The main results of this study are contained in this section.

The most important factor examined was people's willingness to visit beaches as they become more crowded and as the sand depletes due to erosion. Given that most of the respondents were on summer vacation, the survey was simple. A number of beaches in San Diego, Santa Barbara, and Ventura were selected for study. Every attempt was made to get a representative sample; surveyors moved in a zigzag pattern across the beach, making sure that the overall demographics of the sample (in terms of age, ethnicity, and size of group) corresponded to the overall pattern of that beach. Roughly half of the responses were on weekend periods and half during the weekday, with a heavier concentration on Friday. The time of day and date of the response were recorded along with the responses.

The survey was given by groups of two, who introduced themselves and gave a brief summary of the purpose of the study and pointed out that the survey was conducted for the State of California through San Francisco State University (King, 2001). The results of the survey are presented below.

3.4.1 Beach Usage Survey

Table 3.15 presents the overall results of the survey for the most significant questions, which are listed below.

1. If this beach were twice as crowded as it is now, would you go as often or less often?
2. If this beach were half as wide as it is now, but just as crowded, would you go as often or less often?
3. If this beach were half as crowded as it is now, would you go as often or more often? If more often, how many more days?
4. If parking were easier, would you go as often or more often? If more often, how many more days?

5. If it took you half as much time to get to the beach, would you go as often or more often? If more often, how many more days?
6. If restroom facilities were easy to access, would you go as often or more often? If more often, how many more days?

Table 3.15 Summary of Beach Usage Survey Data

Question	Weighted Means for All Beaches (%)
If it was twice as crowded…?	-24.78
If it was half as wide…?	-29.02
If it was half as crowded…?	6.13
If parking were easier….?	17.18
If it took half the time….?	34.38
If restrooms…	2.49

Source: King (2001)

The weighted[13] means are presented in percentage terms relative to current attendance. Please note that these are averages for the entire sample and some answers vary significantly depending upon the beach or the user. These differences will be discussed below.

As one can see from table 3.15, crowding and beach width are important considerations for beach attendance. **If beaches were twice as crowded as they are now, the average visitor would decrease his or her attendance by about 25%. Beach width appears to be even more important; if the average beach were half as wide, visitors would decrease their attendance by 29%.** Time is the most important factor; if people could access the beach in half as much time, their visitation would increase by 35%. Finally, parking is a factor for some; if parking were easy, attendance would increase by 17%, but as we will see later, responses here vary considerably, depending upon local parking. Restroom access does not appear to be a factor, except perhaps at one beach (discussed below). Conversations with beach goers indicate they are mostly dissatisfied with the cleanliness and availability of bathrooms, but when asked if cleaner

[13] For each party, the first question was "How many people are in your group?" Although people were asked if everyone in the group had the same preferences, clearly all individuals differ. It is reasonable to conclude that the answers for large groups should be weighted higher than small groups, but not proportionately so, since the error term for responses in large groups will be higher (commonly referred to as heteroskedasticity). Thus, each observation was multiplied by the square root of n, where n represents the number in each group. The unweighted averages are presented in the appendix and do not differ significantly.

or more accessible restrooms would influence their decision to visit, all but a small percentage (2.5%) say it wouldn't.

3.4.2 The Economic Impact of Beach Erosion in North San Diego County

Beach erosion is particularly severe in north San Diego County, especially at the beaches between Oceanside and Del Mar. Some of these beaches are already eroded to the point where, at high tide, no beach, or at best only a few yards of beach, are left. Although the exact rate of erosion depends upon storms and other natural events, it is clear that the beach is eroding and within ten years there will be a substantial loss. This section will quantify the loss in terms of attendance and tax dollars lost. Sustaining current beach widths yields substantial benefits.

Table 3.16 Attendance at Major North San Diego County Beaches

Beach	Annual Attendance (thousands)	% Day Visitors	% Overnight Visitors
Carlsbad City and State	1,200	70	30
Beacons (Encinitas)	438	90	10
Stone Steps (Encinitas)	292	90	10
Moonlight (Encinitas)	2,263	70	30
San Elijo (Solana)	325	90	10
Cardiff (Solana)	175	90	10
Del Mar	1,560	70	30
Torrey Pines State	700	70	30
Torrey Pines City	750	75	25
Total (or Avg. %)	**7,703**	**73.7**	**26.3**

Table 3.16 gives the official attendance numbers for the most recent full year (2000) at major north San Diego county beaches, including the breakdown between day-use and overnight visitors. The information was obtained from city officials and from the California Department of Parks and Recreation. Overall, the area receives close to eight million beach visitors annually; just over 25% of visitors stay overnight at local hotels and condominiums.

Using the figures for spending for day trips and overnight trips presented in the preceding section, Table 3.17 estimates the expenditures at each beach in 2001 dollars. The total estimated expenditures are just over half a billion dollars per year: $562 million.

Table 3.17 Expenditures at Major North San Diego County Beaches

Beach	Annual Attendance (thousands)	% Day Use	% Overnight Use	Estimated Expenditures Day Trips	Estimated Expenditures Overnight Trips	Total Expenditures
Carlsbad City and State	1,200	70	30	$ 30,936,150	$ 62,763,228	$ 93,699,378
Beacons (Encinitas)	438	90	10	$ 14,517,893	$ 7,636,192	$ 22,154,085
Stone Steps (Encinitas)	292	90	10	$ 9,678,595	$ 5,090,795	$ 14,769,390
Moonlight (Encinitas)	2,263	70	30	$ 58,340,422	$118,360,987	$176,701,410
San Elijo (Solana)	325	90	10	$ 10,772,409	$ 5,666,124	$ 16,438,534
Cardiff (Solana)	175	90	10	$ 5,800,528	$ 3,050,990	$ 8,851,518
Del Mar	1,560	70	30	$ 40,216,995	$ 81,592,196	$121,809,191
Torrey Pines State	700	70	30	$ 18,046,087	$ 36,611,883	$ 54,657,970
Torrey Pines City	750	75	25	$ 20,716,171	$ 32,689,181	$ 53,405,353
Total (or Avg. %)	**7,703**	**73.7**	**26.3**	**$209,025,253**	**$353,461,579**	**$562,486,832**

To estimate the future attendance at these beaches, we adjusted for future population increases using projections from the California Department of Finance, which projects that the population of San Diego will grow by 1.56% per year over the next ten years while the state population will grow at a slightly slower rate: 1.42%.[14] Since visitors to San Diego come from all over the state (and from other states), but are more likely to be local, we used an average population increase of 1.49%.

The second factor accounted for was erosion and the effects of crowding. We assume that, without maintenance, the beaches in north San Diego will erode at 3% per year. It should be noted that this is not a forecast, but a scenario based on interviews with a number of coastal engineers, geologists and other consultants familiar with the area. It should also be stressed that erosion does not occur in a uniform manner, but can be severe at one beach (e.g., Carlsbad) and subtler at another beach. Please note that these differences will only exacerbate our estimates and we believe that this scenario is both plausible and credible given our current limited knowledge of erosion at these beaches.

Even without erosion, beaches in San Diego County will become more crowded due to increases in the population. Further, our survey results indicate two distinct issues: **(1) beach visitors, with very few exceptions, would prefer it if California's beaches were less crowded, and in particular, many said that further crowding would discourage them from visiting; (2) at already-narrow beaches like Carlsbad, many people responded that further erosion would**

[14] California Department of Finance, 1998. *County Population Projections with Age, Sex, and Race/Ethnic Detail*. Sacramento California, December.

deter them from visiting, even if the density of the crowds was maintained. These effects can be analyzed using a concept economists refer to as elasticity. We estimated two elasticities:

1. the elasticity of demand with respect to crowding, which measures the percentage change in visitor demand as the beach becomes more crowded, and
2. the elasticity of demand with respect to beach width, which measures the percentage change in visitor demand as the beach becomes narrower, holding the density of visitors constant.

Both of these elasticities are negative—as beaches become more crowded and narrower, people are less likely to go. Our results also indicate that visitors in north San Diego County are particularly sensitive to both these issues, far more than at the beaches surveyed in other counties (and by a statistically-significant amount). This result is not surprising, given the already-narrow width of these beaches.

- For our calculations, we used the average percentage for all state beaches surveyed in Southern California. Note that respondents at eroded beaches (such as those in north San Diego County) actually had higher values—so our estimate is conservative.
- We estimate that the elasticity of demand with respect to crowding is (–0.3); if the beach becomes twice as crowded (a 100% increase) people will reduce their visits by 30%.
- We estimate that the elasticity of demand with respect to beach width is much higher: 0.7. If the beach becomes half as wide (a 50% decrease) people will reduce their visits by 35%.

Using these estimates of elasticity, Table 3.18 presents our best estimates for attendance at beaches in north San Diego County given two different scenarios.

- In the first scenario, the current beach width will be maintained; given increases in population; this implies more crowding.
- Scenario two examines attendance if erosion occurs at a constant rate of 3% a year. While erosion does not occur at a constant rate, the overall estimates are quite reasonable and conservative, given the rapid rate of erosion on some of these beaches.

Our estimates indicate that sustaining beach width will provide the opportunity for an additional 49.7 million beach visits over ten years in north San Diego County alone.

Table 3.18 Estimated Attendance if Width Maintained Versus Width Reduced

Year	Attendance if Width Maintained	Attendance with Erosion
2000	7,703,000	
2001	7,803,832	6,438,162
2002	7,905,984	5,484,777
2003	8,009,474	4,768,140
2004	8,114,318	4,231,490
2005	8,220,534	3,831,700
2006	8,328,141	3,536,003
2007	8,437,156	3,319,504
2008	8,547,599	3,163,287
2009	8,659,487	3,052,982
2010	8,772,839	2,977,672
Total	**90,502,365**	**40,803,718**
Attendance Loss		**49,698,647**

Naturally, differences in attendance will generate differences in spending and taxes. Table 3.19 presents estimates of total spending at beaches in north San Diego County with current beach width sustained and with erosion. We estimate a loss of over $2.8 billion in spending (undiscounted). The loss in tax revenues estimated are also substantial—over a billion dollars in revenue. The present value of state, local and federal taxes lost is estimated at $851 million. In other words, sustaining current beach widths in north San Diego County alone will generate a present value of $851 million in tax revenue over the next ten years for the state. Please note that these figures do not include enhanced property values to owners of private property who may also benefit from beach restoration. [15]

[15] We use the attendance numbers presented in Table 3.18. We assume real spending per visitor will increase by 2.5% per year and we discount at a 5% rate. All values are in 2001 dollars.

Table 3.19 Total Spending with Beach Width Sustained Versus with Erosion

Total Spending if Width Maintained	$6,608,156,828
Total Spending if Beach Erodes	$3,734,894,441
Loss in Spending	$2,873,262,386

Table 3.20 Estimated Taxes (2000-2010) With and Without Beach Maintenance

Type of Tax	Width Maintained	Erosion	Reduction in Tax
State Taxes	$ 498,854,151	$ 289,058,401	$ 209,795,750
Federal Taxes	$1,292,558,814	$ 748,966,373	$ 543,592,441
Local Taxes	$ 232,894,556	$ 134,949,519	$ 97,945,037
Total	$2,024,307,521	$1,172,974,293	$ 851,333,228

3.5 Other Benefits Associated with Beach Nourishment

3.5.1 Environmental Benefits

California's beaches provide habitat for numerous species both onshore and offshore. Species dwelling in sandy beach habitats also provide an important source of food for shorebirds, seabirds, marine mammals and fishes. Among the species supported by California beach habitats are two endangered bird species: the least tern and the western snowy plover. Sandy beach habitat is also crucial for one fish species, the California grunion, which lays its eggs in the sand.[16] Dugan found that exposed sandy beaches in Southern California "harbor a high diversity, abundance, and biomass of macroinvertebrate species" and are generally richer, in terms of biodiversity, than similar beaches elsewhere in the world, in particular, in Africa, Australia, Chile, and Oregon.[17]

By preserving sandy beaches, beach nourishment projects aid in the preservation of species, such as the snowy plower, grunion, and least tern, that are dependant on this particular type of habitat. The U.S. Department of the Interior has identified 157 current or historical breeding grounds for the snowy plower; of these, 133 are on California beaches.[18] It is not possible to quantify the exact benefit, but there would be a significant benefit from beach nourishment to the snowy plover and some other wildlife dependent upon beaches.

[16] See Dugan, Jennifer, et al., unpublished. *Microfauna Communities of Exposed Sandy Beaches on the Southern California Mainland and Channel Islands*.
[17] *Ibid*.
[18] See "Designation of Critical; Habitat for Pacific Coast Population of the Western Snowy Plover," Department of the Interior, *Federal Register*, December 7, 1999.

Though beach nourishment projects do disturb some species, notably those that reside in the sand or reefs and are relatively immobile (e.g. some small crabs), the limited research on the effects of nourishment indicate that any damage is temporary—the communities revive. Further, several studies in the southern United States indicate that nourishment projects may benefit certain threatened plant and animal species by enlarging and creating habitat.[19] Nourishment projects are designed to minimize any environmental impacts on local species. For example, no project will be conducted when grunion are spawning.

In addition, beaches provide an important form of outdoor recreational activity for humans, particularly in southern California, where parks, lakes and other outdoor recreational opportunities are already stressed. Numerous studies indicate that people who engage in outdoor activity are more likely to be sensitive to environmental issues, compared to people who do not recreate outdoors.[20]

3.5.2 Public Safety Benefits

Beach nourishment also provides a number of collateral public safety benefits to residents and visitors. Wide beaches can minimize bluff collapse, which can lead to injuries and loss of life, particularly during storms. Nourished beaches provide a buffer against damaging storm waves. California experiences numerous severe storms every decade, and the benefits of beaches in mitigating the effects of storm waves are well documented. Beach nourishment provides a sandy bottom for recreational swimmers and surfers, which reduces foot and other injuries caused by wading on rocky shores. Finally, in areas where erosion has completely worn away sandy beaches, a nourishment project can provide safer access to the water; this is a particular issue for surfers, who often wade in from rocky areas.

[19] See National Research Council, 1995. Beach Nourishment and Protection. Washington, D.C. National Academy Press.

[20] For example, see American Recreation Coalition, 1999. Outdoor Recreation in America. www.funoutdoors.com/research.html.

3.6 Conclusions

Recreation is becoming an increasingly important source of spending for Americans and beaches represent one of the most important forms of outdoor recreation in California. A statewide survey indicates that 67% of all residents go to the beach at least once a year and many go much more often. Including out-of-state attendance, we estimate that, in 2001, California experienced 659 million visitor days. Further, total spending on beach-related leisure, tourism and recreation amounted to $61.3 billion in 2001; out-of-state and foreign visitors accounted for 36.4% of this spending.

California's beaches generate an enormous amount of tax revenue for the federal government and for the State of California. We estimate that beaches in the state generate $13.6 billion in federal tax revenues, 66% of the total tax generated, and $4.6 billion in state taxes, 22% of all taxes generated by beach spending. Although precise estimates of local taxes generated are difficult to estimate, local taxes generated are significantly smaller than state or federal taxes. California city and county taxes are roughly 12% of all taxes. However, the benefits to local communities are smaller than benefits to either the state or federal government, since approximately half of all beach-related spending occurs away from the beach community. If we account for this factor and consider city taxes, only about 3% of all taxes generated go to local communities, who must provide a substantial amount of increased services to beach visitors, such as police and lifeguards.

A large number of beach-related projects provide significant economic benefits to the state (King, 2000). In many cases, the ratio of benefits to costs for these projects was greater than ten to one.

Overcrowding is becoming a serious problem at southern California beaches. In a survey conducted in summer 2000, most people indicated that the beaches were overcrowded, and they would reduce their attendance if the crowds continued. In the case of north San Diego County, where many beaches are already severely eroded and continuing to erode, we estimate that the state will lose $210 million in tax revenues if beaches erode beyond their current width. If one includes all tax revenues, the loss is estimated at $851 million.

California's beaches also provide habitat for numerous species both onshore and offshore. Dugan found that exposed sandy beaches in southern California "harbor a high diversity, abundance, and biomass of macroinvertebrate species" and are generally richer, in terms of biodiversity, than similar beaches elsewhere in the world, in particular, in Africa, Australia, Chile, and Oregon. By preserving sandy beaches, beach nourishment projects aid in the preservation of species, such as the snowy plower, grunion, and least tern. In addition, beaches provide an important form of outdoor recreational activity for humans, particularly in southern California, where parks, lakes and other outdoor recreational opportunities are already stressed. Numerous studies indicate that people who engage in outdoor activity are more likely to be sensitive to environmental issues, compared to people who do not recreate outdoors.

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Part 2

4. NOURISHMENT CONCEPTS

Simply stated, beach nourishment is the introduction of sediment onto a beach. In most cases, the sediment is sand and the beach is in an eroded condition. The process supplements the diminishing supply of natural sediment. Nourished shorelines provide two primary benefits: increased area for recreation, and greater protection against coastal storms. Other tangible benefits include tourism revenues, restored wildlife habitats, enhanced public health and safety, increased coastal access, and reduced need for hard structures.

Sediment characteristics and sources, sediment placement methods, and maintenance requirements, the key components of nourishment projects, are discussed in the following sections.

4.1 Overview

Whereas structural means of beach retention were common 30 to 50 years ago, beach nourishment has become the preferred method in recent decades. Beach nourishment represents a “soft” method of shoreline stabilization, in contrast to “hard” alternatives such as groins. Hard structures are designed to remain stable and stationary, fully resisting the actions of waves, currents, and sediment transport. Hence, they tend to be large structures and may significantly impact the natural movement of sand. Soft stabilization alternatives, such as sand or cobble beach fills, mimic nature and are intended to be dynamic, responding to changes in wave and current conditions. In the case of beach nourishment with sand, the dry beach may become narrow during winter storms and then recover much or all of its original width under milder summer wave conditions. Ideally, a beach nourishment project is designed so that this range of seasonal shoreline fluctuation remains within acceptable limits during the project design life. Ultimately, however, nourishment material is sacrificial in nature and will require periodic maintenance.

Introducing new sand onto the beach can compensate for a reduced sediment supply delivered by rivers and streams. In this way, beach nourishment represents a means of restoring a more natural system. Wider beaches, in turn, reduce the need for hard structures while simultaneously increasing recreational opportunities.

4.2 Beach Nourishment Material

The characteristics of the available fill material are of utmost importance in the design of beach nourishment projects. At a minimum, the sediment must be uncontaminated and have a small fraction of fine grain sizes (“fines”, such as silt and clay). Most nourishment projects use sand as the fill material, although projects have been implemented using pebbles and cobbles.

In addition to the foregoing properties, the fill material should possess grain sizes that are comparable to or larger than those of the native beach sand. Comparably sized grains will tend to behave in a manner analogous to that of the native material, while larger grain size will tend to be more stable. Smaller grains should be avoided whenever possible, as they are less stable and hence prone to accelerated erosion.

4.3 Sediment Sources

Sources of nourishment material may include offshore deposits, inland areas, sediment accumulations from within the littoral system, and “sand of opportunity” (NRC, 1995). Each of these sources is described in one of the sections that follow.

4.3.1 Sand of Opportunity

The majority of beach nourishment projects conducted in California have utilized “sand of opportunity”, which is derived from projects whose primary motive is not beach replenishment. Common sources of this material have been dredged sediment from harbor construction, harbor maintenance, and lagoon restoration projects (Wiegel, 1994). In these cases, the suitability of the sediment as a beach fill material must be carefully examined both in terms of size fraction and pollutants. The primary advantage of sand of opportunity is the low cost. By placing the sediment on the beach, offshore disposal costs are eliminated and the nourishment project provides a tangible benefit from the dredging operation.

4.3.2 Offshore Sources

During recent decades, offshore sand deposits have served as the most common source of borrow material. Sand from these relict deposits is typically dredged and placed on the dry beach. The primary advantages of this approach include low cost, high placement rates on the receiving beach, and minimal disturbance onshore while the project is underway.

Although the use of offshore sand deposits also has disadvantages, careful planning and coordination with resource and regulatory agencies can minimize the potential drawbacks. One such drawback is the tendency for offshore sediments to contain a higher percentage of silt and clay, necessitating a large overfill volume to account for anticipated losses. Additionally, the offshore borrow areas must be sited well seaward of the active portion of the beach profile so that the nourishment sand is not drained back into the borrow area by waves and currents.

4.3.3 Inland Sources

There are a number of inland sources of beach-quality sand. In southern California, the loss of sediment reaching the coast due to the damming of rivers is a well-documented phenomenon (Chapter 7, this report). The sediment trapped behind the dams represents a significant source of nourishment material. The use of this sediment accomplishes two objectives: re-establishment of the reservoir capacity and nourishment of the beaches. Other inland sources that have been exploited in the past include sand dunes and deserts.

4.3.4 Sources within the Littoral System

Sand bypassing and backpassing operations redistribute sand within the littoral system. Neither method represents a true source of sand because no new material is added to the system. However, both operations have been utilized extensively in California to place sand where it is most needed.

Sand bypassing is the practice of transporting accumulated sand from the upcoast side of a sediment barrier, such as a jetty, to the eroded side. The process attempts to restore the natural downcoast flow of sand. Many harbors in California conduct sand bypassing in conjunction with maintenance dredging operations.

Sand backpassing involves the mechanical transport of material from a wide stable beach to an upcoast sediment-starved beach. This method often is utilized in locations where the sand from an eroding reach moves alongshore and is deposited in a more sheltered area. Backpassing essentially “recycles” the sand back to the eroding beach. If the sand volumes are moderate and the haul distances are short, the practice can provide a cost-effective scheme for beach maintenance. Similar to sand bypassing, the process must be conducted on a regular basis.

4.4 Beach Fill Placement

Once sand is placed on the beach, waves and currents redistribute the material offshore and alongshore until a stable configuration is achieved. Depending on local conditions, a nourished beach may take several months or years to reach the equilibrium condition.

The fill may be placed well above the shoreline as dune nourishment, on the dry beach and near the waterline, across an extended portion of the profile that stretches from the dry beach to well offshore, or completely offshore as a sand bar (NRC, 1995). In some cases, hard structures may prolong the life of the nourishment material. The various placement strategies are discussed below.

4.4.1 Dune Nourishment

Dune nourishment (Figure 4.1) is particularly effective in protecting upland development against storm waves. The placement of material high above the waterline does not expand the width of the dry beach, however, and therefore is not appropriate when the enhancement of recreational opportunities is an important project objective.

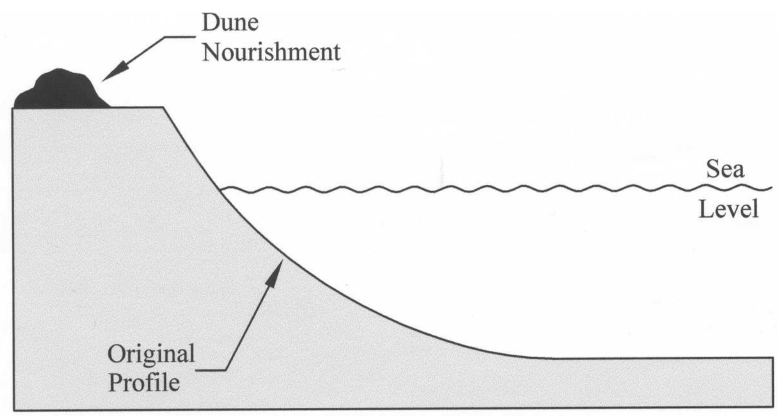

Figure 4.1 Dune nourishment

4.4.2 Dry Beach Nourishment

Nourishment of the dry beach is a very common approach. In this scheme, sand is placed on the dry portion of the beach and near the waterline, and results in an immediate increase in beach width available for recreation (Figure 4.2). However, because no sand is placed on the submerged portion of the beach, sand will be redistributed offshore across the entire profile until a stable configuration is established. The equilibrating process results in a substantial narrowing of the initial dry beach width.

The loss of sand from the beach face, sometimes rather quickly, has been a major source of criticism of beach nourishment projects in the past. This misunderstanding about the redistribution of the fill sand could be eliminated by better public education on the part of coastal engineers, scientists, and planners. It should be made clear that the sand will adjust to a more stable configuration resulting in a substantial narrowing of the initial beach width. However, the project is designed so that the desired beach width is provided after the sand has been re-worked by waves and currents, and this narrower design width should be the public expectation.

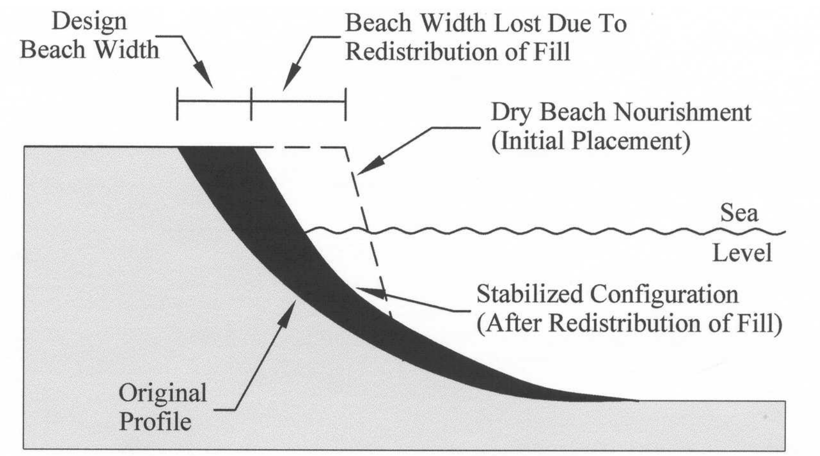

Figure 4.2 Dry beach nourishment

4.4.3 Profile Nourishment

Profile nourishment involves placing the sand across the entire beach cross-section, both above and below water (Figure 4.3). The placement method attempts to build the beach in an already-stable configuration. Because the equilibrium condition develops immediately, there is little offshore redistribution of sand and changes in the dry beach width are minimal. However, this placement scheme is more difficult and also provides less storm protection because there is no extra reserve of sand on the beach as there is with the dune and dry beach nourishment schemes.

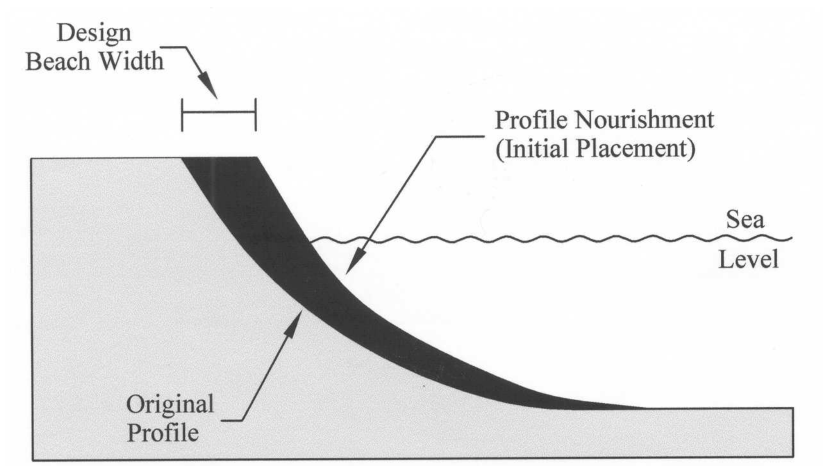

Figure 4.3 Profile nourishment

4.4.4 Nearshore Bar Nourishment

This method involves the placement of beach fill material in a sand bar just offshore of the surf zone (Figure 4.4). To be successful, the placement must be within the active portion of the beach profile. The sand will gradually move onshore under the influence of waves and currents, increasing the beach width. The period of time required for the sediment to be moved up onto the beach varies with wave conditions. Although the nearshore bar placement scheme is the most technically challenging, it may be the most cost-effective alternative.

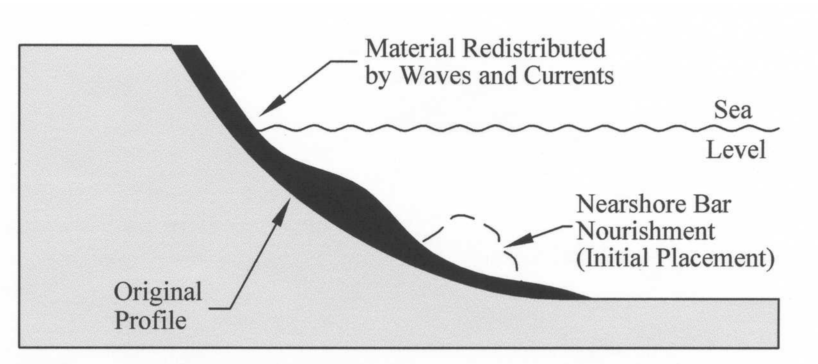

Figure 4.4 Nearshore bar nourishment

4.4.5 Beach Nourishment with Sand Retention Devices

Sand retention devices are often used to prolong the effectiveness of a beach nourishment program (USACE, 1995). These devices are designed to reduce the amount of fill lost alongshore or offshore. Examples of natural sand containment are common in California. Many naturally-wide beaches exist where sand is retained by sediment-blocking features such as headlands, reefs, rocky stream deltas, and other irregular bottom contours (Everts, 2000). In concept, the use of sand retention devices with nourishment is appealing; however, it should be considered cautiously. Undesirable effects, including accelerated erosion at adjacent downcoast beaches and loss of nearshore recreational opportunities, may result if these devices are not utilized properly.

4.5 Maintenance

As indicated at the outset of this chapter, nourished beaches typically require periodic replenishment. Waves and currents will redistribute the beach fill sand in the alongshore and cross-shore directions, background erosion may persist, and extreme storm events may cause large losses of sediment from the dry beach. As a result, maintenance should be scheduled in the original project plan and monitoring should be performed to insure that the maintenance schedule is appropriate. Typical re-nourishment intervals range between two and ten years.

Depending on local site conditions and sediment availability, it may be more economical to place a smaller fill initially and perform frequent re-nourishment. Conversely, if the beach fill project is dependent on a single large dredge project in a nearby navigation channel, then a larger initial fill will be placed and the interval between maintenance operations will be greater.

4.6 References

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5. PUBLIC BEACH RESTORATION PROGRAM

The Public Beach Restoration Program (PBRP) was created in 1999 by Assembly Bill 64 (Ducheny; Public Beach Restoration Act). A motivating factor behind the legislation was the continued loss of public beach due to man's activities in upland watersheds and along the shoreline. The PBRP is administered by the Department of Boating and Waterways (DBW).

5.1 Overview

The Public Beach Restoration Program provides a funding vehicle for the legislature to support restoration, enhancement, and maintenance of one of California's most valued resources – the beaches.

During the past century, intense coastal and inland development have significantly impacted California's beaches. Dams, debris basins and stream channelization have decreased the natural sediment supply to the coast, while harbor structures have interrupted alongshore sand movement. Consequently, many public beaches are eroded, unable to meet growing recreational demands.

Public beach loss will continue without beach nourishment. Already-narrow beaches will be further strained to meet the increasing needs of the growing population. Many of the broad beaches enjoyed today were produced by beach nourishment programs. However, the number of nourishment projects conducted in California has decreased dramatically in recent decades. These wide beaches have begun to narrow, and will continue to do so without sand replenishment. The implications of continued beach erosion include diminished recreational opportunities, lost tourism revenues, and increased damage from coastal storms, such as those that occurred during the 1997-98 El Niño winter.

A key component of the PBRP is the promotion of both local and federal partnerships with the state. On the local level, the DBW has joined with regional management agencies such as SANDAG (San Diego Association of Governments) and BEACON (Beach Erosion Authority for Clean Oceans and Nourishment) to support beach nourishment projects. A federal partnership has been forged with the U.S. Army Corps of Engineers (Corps). In 2001, the DBW coordinated nine projects with the Corps. A typical Corps project uses a multi-phase approach, and may have a life of 50 years. The project commences with a reconnaissance study, followed by a detailed feasibility study, an engineering and design phase, and, finally, construction. In 2001, the initial construction phase was cost-shared on a 65 % federal /35% nonfederal basis. If necessary, costs of maintenance phases are shared on a 50/50 basis.

5.2 Activities Undertaken Through the Public Beach Restoration Program

Funding for the initial year of the program (fiscal year 1999-2000) was limited to $500,000. These funds were used to support beach nourishment projects and studies in San Francisco, Santa Cruz, Ventura, Huntington Beach, and San Diego.

The state budget for fiscal year 2000-2001 provided $10 million in grants to be administered by the DBW, representing a substantial funding increase over prior years. Following a review of grant applications submitted by local agencies, funds were allocated for 16 beach related projects. The projects are summarized briefly in Table 5.1.

Table 5.1 Projects and Funding for the Public Beach Restoration Program (FY 2000-01)

Recipient	Project	Funding
City of San Francisco	Nourishment at Ocean Beach	$1,000,000
BEACON	Nourishment at Goleta County Beach[2]	$650,000
City of Carpinteria	Corps feasibility study of beach nourishment alternatives at city beaches [1]	$200,000
City of Port Hueneme	Dune restoration and vegetation at city beach park	$129,500
Los Angeles County	Partial funding for the Coast of California Storm and Tidal Waves Study-LA County	$500,000
City of Long Beach	Corps feasibility study of beach nourishment at Peninsula Beach [1]	$100,000
City of Seal Beach	Corps feasibility study of alternatives to increase nourishment intervals at Surfside-Sunset [1]	$113,750
Surfside-Sunset Project	Nourishment at Surfside-Sunset feeder beach [1]	$3,850,000
City of Huntington Beach	Corps feasibility study of beach nourishment alternatives at Huntington Cliffs [1]	$255,250
City of Newport Beach	Nourishment feasibility study at Balboa Island, Newport Bay	$40,000
City of San Clemente	Corps feasibility study of beach nourishment alternatives at city beaches [1]	$425,000
SANDAG Regional Beach Restoration Project	Nourishment at 12 beaches in San Diego County [2]	$1,236,500
City of Encinitas[3]	Corps feasibility study of beach nourishment alternatives at city beaches [1]	$400,000
City of Solana Beach[3]	Corps feasibility study of beach nourishment alternatives at city beaches [1]	$400,000
City of Imperial Beach	Corps feasibility study of beach nourishment at city beaches[1]	$200,000
Scripps Inst. of Oceanography	Southern California Beach Processes Study	$500,000

[1] Matching funds [2] Supplemental funds [3] The Encinitas and Solana Beach studies will be combined

The grants awarded for the 2000-2001 fiscal year will support projects ranging from local and regional beach nourishment programs to Corps feasibility studies. As shown in Table 5.2, the majority of the program budget, approximately 69%, will be used to conduct beach nourishment projects. Cost-shared projects with the Corps constitute 26% of the program budget, with the remaining funds to be used for additional research into beach erosion and California coastal processes.

Table 5.2 Funding Allocation for the Public Beach Restoration Program (FY 2000-01)

Project Category	*Number of Projects*	*Total Funding (FY2000-2001)*	*Percentage of Program Budget*
Beach Nourishment and Restoration	5	$6,866,000	69%
Corps of Engineers Projects	9	$2,594,000	26%
Research and Other Studies	2	$540,000	5%
Total	*16*	*$10,000,000*	*100%*

5.2.1 Annual Nourishment at Ocean Beach, San Francisco County

Grant Recipient: City and County of San Francisco
Grant Amount: $1,000,000
Project Type: Beach Nourishment

Background

Severe winter storms have caused increased beach and seacliff erosion at Ocean Beach, San Francisco. The highest rates of erosion have occurred between Sloat Boulevard and Fort Mason. Several public improvements have been threatened, most notably the Great Highway and an underground sewer transport structure (CCSF, 2000).

In an attempt to limit erosion, rock revetments were constructed at several locations along the Great Highway during the early 1990's. However, continued erosion along unprotected portions of the seacliffs and waning public support for the use of hard structures prompted the city to pursue alternative long-term solutions. Proposed alternatives have included constructing offshore reefs, restoring a sand dune system, building seawalls, and managed retreat and relocation of the Great Highway.

A beach nourishment program was implemented as a short-term solution. Nearly 10,000 cubic yards of material were placed on the beach in September 1999. Renourishment operations conducted in 2000 provided an additional 7,000 cubic yards of sand. The fill material was barged from a shoal off of Angel Island in the Bay. The 1999 and 2000 nourishment episodes were conducted for a cost of $500,000 and $450,000, respectively (Burke, 2001).

In both cases, the sand was placed against the bluff base to create a protective barrier. The majority of the nourishment material was eroded during the winter storm season. However, bluff recession was minimized.

Planned Project

A portion of the grant provided by the PBRP will support the annual re-nourishment of Ocean Beach from 2001 to 2003. Additionally, the local cost share for a planned Corps study will be partially funded by the grant.

Initial beach fill activities were scheduled for Fall 2001, with the placement of nearly 8,000 cubic yards of material. Similar to the previous nourishment operations, sand would be placed along the base of the bluffs (above the Mean High Water Line). A 60- to 70-ft wide sand berm would protect 250 feet of bluff and public development over the 2001-2002 winter (CCSF, 2001). The material would serve as a sacrificial barrier, which may be lost completely during the storm season. The estimated project cost was $450,000.

5.2.2 Nourishment at Goleta Beach, Santa Barbara County

Grant Recipient: BEACON
Grant Amount: $650,000
Project Type: Beach Nourishment

Background

The shoreline along Santa Barbara and Ventura Counties has experienced long-term erosion at many locations. The Beach Erosion Authority for Clean Oceans and Nourishment (BEACON), a Joint Powers Agency, was founded in 1987 to protect and enhance the region's beaches. Since its formation, BEACON has implemented an ongoing coastal monitoring program and has conducted comprehensive studies to better understand the nature of the shoreline erosion occurring within its jurisdiction.

A principal cause of the erosion is human-induced changes to the natural sediment supply system. Construction of dams on the Ventura and Santa Clara Rivers and debris basins on smaller streams has significantly reduced the volume of sand reaching the coast from inland watersheds (Chapter 7, this report). Additionally, the area's four harbors (Santa Barbara, Ventura, Channel Islands, and Port Hueneme) act as littoral barriers, effectively blocking the natural alongshore movement of sand. Periodic sand bypassing has been conducted at each of the harbors in order to mitigate downcoast beach erosion and maintain navigable depths (Noble Consultants, 1989). However, the sediment supply lost from upland (riverine) sources could be offset by introducing new material from an outside source. To address this problem, BEACON has developed a Regional Sand Management Plan.

The primary component of BEACON's sand management plan is the implementation of a large-scale beach nourishment program utilizing sand from offshore borrow sites (BEACON, 2000). The plan calls for periodic nourishment at several "receiver beaches" along the coast. Subsequently, these sites will serve as "feeder beaches" as waves and currents transport the sand alongshore, nourishing downcoast beaches. Unlike traditional beach fill operations, the material will be placed just offshore of the surf zone to form an artificial sand bar. This technique provides an estimated cost savings of over 50% relative to pumping the sand onto the dry beach.

Planned Project

The PBRP grant provided partial funding for a $1.75 million demonstration project at Goleta County Beach to test the effectiveness of the proposed nearshore placement method. The State Coastal Conservancy provided the remainder of the project cost. If successful, the sand would gradually move onshore, nourish Goleta Beach, and eventually migrate south to adjacent beaches. The project site is shown in Plate 5.1.

Approximately 250,000 cubic yards of sediment would be excavated from an offshore sand deposit and transported by hopper dredge to the project site. Previous studies indicate that the borrow site, located 1.5 miles offshore in a water depth of about 60 feet, may contain as much as 24 million cubic yards of sand. Once on site, the hopper dredge would deposit the material in water depths of 15 to 25 feet, forming a sand bar with a crest elevation approximately 10 feet below the sea surface. Operations would be conducted during the late spring or summer, when ocean conditions are conducive to onshore sand movement and safe maritime operations.

The effectiveness of the nourishment project would be monitored over the following year with a series of periodic beach profile surveys. Shoreline changes would be documented at Goleta Beach as well as the adjacent upcoast and downcoast beaches. The monitoring program also would investigate the environmental impacts of the project.

The use of the nearshore placement technique is not unprecedented in California. In 1991, approximately 1.3 million cubic yards of sand were dredged from the Santa Ana River and placed in a nearshore mound off the coast of West Newport Beach in water depths of 15 to 30 feet (Mesa, 1996). Beach profiles were collected periodically to monitor the fate of the nourishment material. The beaches located in the immediate vicinity of the project became wider, reflecting the onshore migration of the sediment.

Plate 5.1 Aerial view of Goleta County Beach, 1998 (photo courtesy of Moffatt and Nichol)

Although the primary objective of the BEACON project is to demonstrate the effectiveness of the nearshore placement method, Goleta Beach was selected specifically to provide immediate protection from chronic erosion at the site. During the 1999-2000 winter season, storm waves eroded approximately 30 feet of the park's grassy area and damaged several irrigation lines. A temporary rock revetment was constructed to limit further damage and preserve recreational opportunities at the park. However, due to public opposition and a negative environmental review by the California Coastal Commission, revetment removal was required, exposing the park to continued damage. If, as predicted, the nourishment material migrates onshore, the increased beach width at the site would provide a buffer against damaging storm waves during the following winter.

5.2.3 Feasibility Study at Carpinteria, Santa Barbara County

Grant Recipient:	City of Carpinteria
Grant Amount:	$200,000
Project Type:	Corps of Engineers Feasibility Study

Background

The Carpinteria shoreline spans over 1 mile of the Santa Barbara County coast and is owned by both the city and the State. The sandy beaches are typically narrow, and backed by public and private developments, state park facilities, and the Santa Monica Creek estuary. Plate 5.2 shows a narrow beach found in the area.

Plate 5.2 Carpinteria Beach near Linden Avenue, February 1987

Erosion problems at the city shoreline began soon after completion of Santa Barbara Harbor in 1929. Despite intentions to minimize adverse effects to the shoreline, the harbor breakwater effectively blocked the alongshore movement of sand. Previously-wide beaches were deprived of sediment, resulting in chronic downcoast erosion. Seawalls and revetments were constructed to protect development at several locations.

A sand bypassing program was implemented in 1933 to compensate for the interruption in natural sediment transport. The operations essentially restored the littoral system to the pre-harbor status-quo, providing enough sand to avoid severe shoreline recession but insufficient quantities to rebuild the eroded beaches.

Upland developments have sustained damages from erosion and coastal flooding on several occasions, including $128,000 in damages following a 1995 storm. In 2001, as many as 14 structures were threatened by recurring erosion. At 2001 erosion rates, estimated at 5 feet/year by the Corps, the structures may be destroyed by 2013 (USACE, 2001). Continued erosion also will limit recreational opportunities at Carpinteria, known unofficially as the safest beach in the world.

Planned Project

The PBRP grant financed a portion of the non-federal cost for a Corps Feasibility Study. The objectives of the feasibility study are (USACE, 2001):

1.) Restore recreational value of beaches;
2.) Preserve and enhance habitat for species dependent upon sandy beaches; and
3.) Reduce coastal storm damage.

Beach nourishment, the Corps' primary alternative, would provide recreational opportunities, the desired habitat, and storm protection. Several offshore borrow sites were known to exist in the area, and would be dredged to acquire the necessary fill material. Both beach face and nearshore bar placement would be investigated. Sand retention devices, designed to prolong the effectiveness of a beach fill, would be considered.

5.2.4 Dune Restoration at City of Port Hueneme, Ventura County

Grant Recipient:	City of Port Hueneme
Grant Amount:	$129,500
Project Type:	Dune Restoration

Background

Severe coastal erosion at Hueneme Beach began in the 1940's following the construction of the Port Hueneme Naval Facility (Noble Consultants, 1989). The arrowhead jetties that stabilize the harbor entrance block the natural alongshore flow of sediment, isolating the downcoast beach from its only natural source of sand replenishment. Channel Islands Harbor, built approximately 1 mile to the northeast in 1960, further contributed to the problem.

The erosion problem is successfully mitigated by a Corps sand bypassing program that transports the sand, impounded updrift of Channel Islands Harbor, to Hueneme Beach on a bi-annual basis. Since the program commenced in the 1960's, approximately 1.19 million cubic yards of sand per year have been placed downcoast of Port Hueneme (Wiegel, 1994). During the 2000 bypassing operation, the Corps nourished Hueneme Beach with 948,000 cubic yards of material (City of Port Hueneme, 2000).

Despite the success of the sand bypassing program, sand loss by aeolian, or wind-blown, processes continues to be a problem for the city of Port Hueneme. A brisk afternoon seabreeze transports sand from the beach onto Surfside Drive and into the adjacent residential areas. The wind-blown sediment creates costly maintenance problems related to street sweeping and road repair.

Installation of a sand retention wall as part of the West Beach Public Promenade Extension provided a partial solution to the wind-blown sediment problem along the western end of Hueneme Beach. Although the wall provides an effective barrier to wind-blown sand from the beach, sediment from small relict dunes located between the wall and the street continues to migrate landward. The eastern portion of Hueneme Beach lacks a sand retention wall, with only an unstable dune field to impede wind-blown sediment.

Planned Project

The city of Port Hueneme planned to implement a dune revegetation project with the funds awarded through the PBRP (City of Port Hueneme, 2000). The objective of the project was to create stable sand dunes, which would provide a natural barrier to wind-blown sediment in upland areas. A similar revegetation project conducted along the far eastern portion of the beach proved successful in stabilizing the dunes and preventing excessive wind-blown sedimentation. Habit restoration is an additional benefit of the project.

The project plan provided for landscaping along the upland side of the West Beach Promenade sand retention wall, the dunes along the eastern portion of Hueneme Beach, and an area between two public parking lots (Lots B and C). Work was scheduled to commence in Summer 2001, with construction performed by city crews over an 8-week period. The PBRP grant funded 85% of the project cost.

5.2.5 Coast of California Storm and Tidal Waves Study – Los Angeles Region

Grant Recipient:	Los Angeles County
Grant Amount:	$500,000
Project Type:	Corps of Engineers Regional Shoreline Study

Background

The Coast of California Storm and Tidal Waves Study (CCSTWS) was authorized by Congress under the Flood Control Act of 1965. The general objective of the CCSTWS is to develop a coastal information database that can be used by federal, state, and local governments, homeowners and beach users to implement rational and well-formulated actions and policies for the California coastal zone.

The study commenced in the San Diego region (Dana Point to the U.S. Mexico Border) in 1983. The South Coast region CCSTWS, addressing the Orange County shoreline between the Los Angeles/Long Beach Harbor Complex and Dana Point, was initiated in 1992 following completion of the San Diego Region CCSTWS. Planning for the next phase of the study, the Los Angeles Region CCSTWS, was progressing in 2001.

Los Angeles County established a Beach Nourishment Task Force in 1999 with the specific objective of developing a long-term, regional plan to manage coastal erosion and beach nourishment along the county coastline. In addition to county officials, the task force includes the Corps, coastal communities, state and federal agencies, and public and private interest groups. It is anticipated that the results from the Los Angeles Region CCSTWS will be the basis of the county's long-term coastal management strategy.

Planned Project

To advance the work of the Beach Nourishment Task Force, the Los Angeles County partnered with the Corps to conduct the Los Angeles region CCSTWS. The PBRP grant provided a portion of the Los Angeles County cost share for the first two years of the five-year, $5.2 million study.

As indicated previously, the general goal of the CCSTWS program is to provide engineers, scientists and policy makers with the information necessary to develop and implement sound coastal management strategies. Specific objectives of the Los Angeles region CCSTWS are (County of Los Angeles, 2000):

- Perform a coastal processes analysis for use in future studies and projects;
- Establish criteria for the quality of beach-suitable nourishment material;
- Identify and characterize potential sources of beach nourishment material;
- Identify areas with long-standing coastal erosion issues and provide recommendations for future projects or studies to mitigate the problems;
- Establish a GIS database that integrates numerical models for predicting long-term shoreline changes and the impacts of pollutant discharges on coastal water quality; and
- Develop a long-term sediment management plan for the Los Angeles region.

The study was scheduled to commence in the 2001-2002 fiscal year. Data acquisition efforts, including installation of wave gauges and collection of beach profile data, began in Fall 2001.

5.2.6 Feasibility Study at Peninsula Beach, Los Angeles County

Grant Recipient:	City of Long Beach
Grant Amount:	$100,000
Project Type:	Corps of Engineers Feasibility Study

Background

The majority of the Long Beach oceanfront is sheltered from storm waves by the offshore breakwaters of the Los Angeles/Long Beach Harbor Complex. At Peninsula Beach, however, ocean waves pass between the eastern end of the breakwater and the Alamitos Bay entrance jetties and proceed unimpeded to the coast, eroding the shoreline (Coastal Frontiers, 1995).

Plate 5.3 Erosion pattern at Peninsula Beach

As shown in Plate 5.3, the typical pattern of shoreline change is sediment erosion at the central portion of Peninsula Beach and deposition on the sheltered beaches located to the west. Approximately 2,500 feet of shoreline, between 59th Place and 71st Place, are subject to active erosion. Shoreline recession approaching 100 feet is not uncommon at some locations during a typical year.

The eroding beach is backed by 93 oceanfront homes and an aging timber bulkhead and boardwalk. When the beach is narrow, these homes and public structures are subject to coastal flooding. Furthermore, recreational opportunities and the associated economic benefits are diminished as the beach becomes narrower.

Several solutions for restoring this section of shoreline have been investigated. Beach stabilization concepts that have been implemented in the past include both sand and gravel nourishment, artificial seaweed installation, a submerged breakwater composed of large sandbags, and a groin field. Shore restoration concepts that have been studied to date include the extension of either the Long Beach Breakwater, the Alamitos Bay Entrance West Jetty, or both; submerged offshore breakwaters; groin fields; segmented offshore breakwaters; and a perched beach (an offshore sill intended to trap sand on the beach).

The city of Long Beach currently conducts an annual re-nourishment program to maintain Peninsula Beach. The program is a backpassing operation that transfers sand from the wide, sheltered beaches in the lee of the Long Beach Breakwater to the narrow, exposed shoreline of Peninsula Beach. A typical nourishment episode transfers between 75,000 and 100,000 cubic yards of sand at an approximate cost of $150,000.

Planned Project

Despite the relatively low cost of the beach nourishment operations, the program has been criticized because the activities must be repeated on a regular basis. In hopes of decreasing the cost of providing annual nourishment and increasing recreation opportunities and the level of storm protection at Peninsula Beach, the city of Long Beach and the Corps plan to conduct a feasibility study of shoreline restoration alternatives (City of Long Beach, 2000). The grant awarded through the Program would provide a portion of the non-federal share of the cost. The total estimated cost for the two-year study program is $800,000.

The general objective of the Corps feasibility study is to develop a long-term solution to the beach erosion problem. Specific objectives of the study are:

- Maintain recreational beach opportunities;
- Preserve and enhance the environment;
- Control beach erosion damage; and
- Reduce coastal storm flood damage.

5.2.7 Surfside-Sunset Nourishment Program, Orange County

Grant Recipient:	State Contribution to Federally-Sponsored Project
Grant Amount:	$3,850,000
Project Type:	Beach Nourishment

Background

The Surfside-Sunset Nourishment Program was initiated in 1964 as a component of the Orange County Beach Erosion Control Project. The goal of the program is to mitigate erosion of Surfside-Sunset Beach, and nourish the Orange County shoreline north of Newport Harbor. To accomplish this objective, periodic beach nourishment is performed at Surfside-Sunset Beach, which then functions as a "feeder beach" as waves and currents transport sand alongshore and nourish the downcoast beaches. The project is funded jointly by the Corps, Orange County and the State of California (through the DBW).

Major alterations to the natural condition of the San Pedro littoral cell began in 1889 with construction of the Los Angeles/Long Beach Harbor Complex. Additional harbor development and navigation projects at the San Gabriel River mouth and Anaheim Bay effectively extended erosion to Surfside-Sunset Beach by the mid-1940's. Inland development, particularly flood control projects, also contributed to the changes in the natural condition of the beaches.

This extensive development significantly impacted the coastal processes of the region. Some beaches benefited from these changed conditions while others did not. Erosion was particularly severe along the beaches fronting the communities of Surfside-Sunset Beach and West Newport Beach, where wave action has caused coastal flooding and property losses.

The initial nourishment effort conducted under the Surfside-Sunset Project was completed in June 1964 and provided 4 million cubic yards of beach sand. Subsequently, between 1971 and 1997, over 10 million cubic yards of additional sand were placed on the Surfside-Sunset feeder beach. Although the initial replenishment utilized material from within the Naval Weapons Station, the majority of the sand placed since 1979 originated from nearshore borrow sites. Plate 5.4 shows wide beaches at Surfside-Sunset and Bolsa Chica two years after a nourishment operation.

Plate 5.4 Surfside Sunset and Bolsa Chica Beaches, August 1986.

A primary component of the South Coast Region (Orange County) CCSTWS was an evaluation of the Surfside-Sunset nourishment project. A detailed analysis of beach widths and sediment volumes between 1963 and 1997 indicated that the vast majority of nourishment material placed on the beach has remained in the littoral system (USACE, 1999). Furthermore, beach widths throughout the region were found to increase at an average rate exceeding 4 feet per year.

Planned Project

A portion of the non-federal contribution for the Surfside-Sunset nourishment effort was provided by the PBRP grant. The balance of the $13 million project would be funded by the Corps and Orange County. Operations were scheduled to begin in October 2001 and be completed within four months.

An estimated 1.8 million cubic yards of sand would be excavated from an offshore borrow site, using conventional hydraulic dredging equipment, and pumped onto Surfside-Sunset Beach (Mesa, 2001). The nourishment material would be placed between the east jetty of Anaheim Bay and Anderson Street in Sunset Beach, a distance of approximately 3,500 feet. The resulting beach width would be approximately 500 feet, increasing the recreational opportunities at Surfside-Sunset Beach.

The borrow site is located offshore of Bolsa Chica in water depths of 42 to 55 feet. Geotechnical investigations indicate that the offshore site potentially contains 2.5 million cubic yards of suitable nourishment material. Sources of beach-quality sand located in closer proximity to Surfside-Sunset Beach were exploited during previous project phases, thereby necessitating the large transport distance for the current nourishment episode.

5.2.8 Feasibility Study at Surfside-Sunset Beach, Orange County

Grant Recipient:	City of Seal Beach
Grant Amount:	$113,750
Project Type:	Corps of Engineers Feasibility Study

Background

The ongoing chronic erosion at Surfside-Sunset Beach is directly attributable to extensive coastal development in Los Angeles and Orange Counties. Historically, Surfside-Sunset Beach benefited from the natural longshore drift that delivered sediment from the nearby Los Angeles and San Gabriel Rivers and upcoast beaches. However, following construction of flood control measures on these rivers, construction of the jetties at Anaheim Bay (for the U.S. Navy Weapons Station, Seal Beach) and the breakwaters of the Long Beach – Los Angeles Harbor Complex, significant changes occurred to the natural condition of the region. Surfside-Sunset Beach, located adjacent to the Naval Weapons Station, was adversely affected by these changes.

Erosion problems at Surfside-Sunset Beach began in the mid 1940's soon after completion of the Naval Weapons Station (City of Seal Beach, 2000). To provide protection for homes along the eroding beach, a revetment was first built by the Navy in 1945 and most recently refurbished in the 1990's. The first beach nourishment operations also were conducted in 1945 (Shaw, 1980). Since that time, over 16 million cubic yards of sand have been placed on Surfside-Sunset Beach. The majority of beach nourishment at the site has been performed under the auspices of the U.S. Army Corps of Engineers Orange County Beach Erosion Control Project.

The Surfside-Sunset Nourishment Program, discussed previously in Section 5.2.7, was implemented as part of the overall Orange County Beach Erosion Control Project. The primary objectives of the nourishment program were to 1) provide shore protection for Surfside-Sunset Beach, and 2) replenish the downcoast beaches with sand. Since the program's inception in 1963, Surfside-Sunset Beach has been re-nourished at intervals of 4-8 years. During the most recent nourishment episode, completed in Fall 1997, approximately 1.6 million cubic yards of sand were added to the beach.

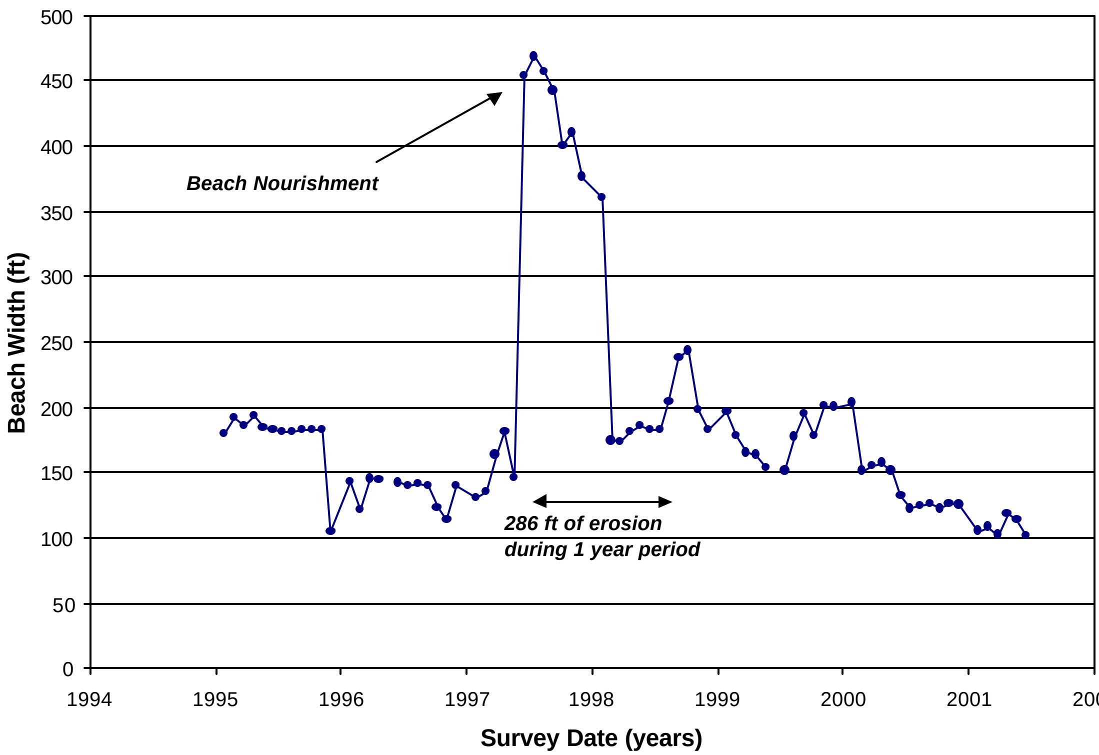

Figure 5.1 Beach width measured at Surfside-Sunset Beach, 1995-2001

Results from the South Coast Region CCSTWS indicate that the Corps' nourishment program has been successful in replenishing the shoreline south of Surfside-Sunset Beach (USACE, 1999). However, wide beaches adequate for recreation and storm protection at Surfside-Sunset are realized for only a short period following nourishment episodes. As indicated in Figure 5.1, which shows monthly beach width measured at Surfside-Sunset Beach preceding and following the 1997 nourishment, the benefits of the beach fill are often lost within the first year of the project. It should be noted that this period encompasses the 1997-98 El-Niño winter.

Between scheduled nourishment episodes, both public and private infrastructure are often at risk in winter storms seasons because of critically-narrow beach widths. The rock revetment that serves as the last line of defense along Surfside-Sunset Beach was exposed by wave action in 1995, three years after the 1992 beach fill was completed, and again in 1999, only two years after the most recent nourishment episode prior to this planned project.

Planned Project

The Corps, in a cooperative effort with the city of Seal Beach, proposed to conduct a feasibility study to investigate shoreline restoration alternatives at Surfside-Sunset Beach. The estimated cost of the two-year study effort was $325,000. The PBRP grant financed 70% of the non-federal cost required for project authorization.

The general goal of the study was to identify measures to restore and preserve the public beach, thereby promoting recreational and economic opportunities and providing protection from damaging coastal storms (USACE, 2000a). Non-structural methods of restoration, such as periodic beach nourishment, are preferred by the city. However, sand retention devices designed to prolong the effectiveness of beach replenishment operations also would be investigated.

5.2.9 Feasibility Study at Huntington Beach, Orange County

Grant Recipient:	City of Huntington Beach
Grant Amount:	$255,250
Project Type:	Corps of Engineers Feasibility Study

Background

Huntington Cliffs span approximately 8,000 feet of coastline between Bolsa Chica State Park and 17th Street in Huntington Beach. As shown in Plate 5.5, the northern and southern portions of the reach contain relatively wide sandy beaches, while the central portion is characterized by narrow beaches backed by high coastal bluffs (USACE, 1995). The bluffs in the central portion form a mild promontory, extending further seaward than the surrounding coastline.

Plate 5.5 Huntington Cliffs, October 1994 (looking south towards Huntington Beach Pier)

The sandy beaches that protect the bluffs along the northern and southern portions of the reach have become wider since the Surfside-Sunset Nourishment Program was implemented in 1963. In contrast, the narrow beaches fronting the bluffs along the central portion of the reach have exhibited long-term trends ranging from slight recession to stability. The Corps has speculated that the headland or promontory-type feature created by the bluffs prevents the beach from retaining the nourishment material that moves down the coast from Surfside-Sunset Beach (USACE, 1999). Lacking a significant fronting beach, a non-engineered revetment at the base of the bluffs provides the primary protection from ocean waves, which routinely reach the bluffs during high tides (Plate 5.6).

Gradual, long-term bluff erosion along the central portion of Huntington Cliffs has resulted in facilities losses at Huntington Beach Blufftop Park (City of Huntington Beach, 2000). Damages to security lights, safety railings, and pedestrian walkways have been documented. Parking lot facilities are currently threatened, and continued erosion may eventually impact the Pacific Coast Highway. Public safety issues and lost recreational opportunities resulting from damaged park structures and a persistently-narrow beach are major concerns to the city.

Plate 5.6 Non-engineered revetment at base of bluffs, October 1994

Planned Project

The PBRP grant financed a portion of the non-federal cost contribution required to conduct a Corps Feasibility Study. The total study costs were estimated to be $1.02 million. The primary objective of the feasibility study was to identify appropriate measures to reduce coastal storm damages to public facilities at the Huntington Cliffs (USACE, 2000b).

Alternatives for limiting bluff erosion and protecting the public facilities at the site include beach nourishment along 4,600 feet of shoreline. Beach widths would be increased by 100 to 200 feet.

5.2.10 Feasibility Study at Balboa Island, Orange County

Grant Recipient:	City of Newport Beach
Grant Amount:	$40,000
Project Type:	Feasibility Study

Background

Balboa is a man-made island located in Newport Bay. The island is enclosed by a sheetpile bulkhead and has narrow, fine-grained beaches along the northern and southern shorelines. With 2.5 miles of public sidewalk and beaches, Balboa Island offers the most extensive public access and recreational opportunities of the eight islands located in the Bay. The public facilities, including 23 boat launch areas, draw over 150,000 visitors each day during the peak summer season (City of Newport Beach, 2000).

Although located in a relatively benign wave environment, the public beaches at Balboa Island are experiencing a gradual net loss of sand. The primary mode of erosion is believed to be the offshore movement of fine sand (Moffatt and Nichol, 1982). The ongoing erosion has reduced recreational opportunities and increased maintenance at public boat slips and piers.

The beaches receive small quantities of nourishment material on an irregular basis. All of the material placed on the beaches is dredged from sites in the Bay, usually during maintenance dredging at shoaled boat slips. The City of Newport Beach budget includes $35,000 annually for dredging and nourishment at public Bay beaches. Private individuals also provide nourishment material as a by-product of maintaining adequate depths at residential boat slips. Permits issued by the Corps limit maintenance dredging quantities, and thus nourishment, to 500 cubic yards per instance.

Planned Project

The City of Newport Beach planned to investigate sand nourishment alternatives for restoring the public beaches at Balboa Island (City of Newport Beach, 2000). Among the alternatives under consideration was a large-scale nourishment project along the eastern and southern shorelines of Balboa Island. Fine-grain sand, dredged from offshore of the island, would be used to form the foundation layer of the fill. In order to create a stable beach, coarse-grained material would then be imported and used to construct the upper layer and seaward portions of the fill. This construction technique was successfully implemented for a project at Alameda in San Francisco Bay. The post-nourishment beach would have an average width of 80 feet.

5.2.11 Feasibility Study at San Clemente, Orange County

Grant Recipient:	City of San Clemente
Grant Amount:	$425,000
Project Type:	Corps of Engineers Feasibility Study

Background

Beach erosion along San Clemente's shoreline has become the source of increasing public concern during the last two decades (City of San Clemente, 2000). Since the severe El-Niño winter of 1982-83, the San Clemente shoreline has been gradually receding. The average beach width in the region has been reduced to approximately 50 feet, nearly half of the pre-El-Niño condition (USACE, 2000c). The 4,500-foot stretch of beach between Mariposa Street and Cristobal Street has experienced the greatest reduction in width during the last decade.

Continuing erosion has subjected both public and private development to damage from coastal storms. During the 1997-98 El-Niño winter, storm waves caused $250,000 in damages to a rip-rap revetment at Capistrano Shores Trailer Court (Plate 5.7). Public facilities, including the Marine Safety Building, restroom facilities, lifeguard stations, and parking lots are threatened during severe winter storms. Further damage to the public rest rooms near the pier may necessitate relocation of the facilities from the beach to the landward side of the railroad tracks.

Plate 5.7 Revetment at Capistrano Shores Trailer Court, June 2001

The railroad corridor passing through the San Clemente area lies between the seacliffs and the ocean (Plate 5.8). Ongoing beach erosion threatens this right-of-way, which has been designated as a Strategic Rail Corridor by the Department of Defense. To protect the railroad tracks during high storm waves and high tide conditions, the Orange County Transportation Authority performs periodic maintenance along an existing rip-rap revetment. Costs to maintain this under-designed revetment have averaged $200,000 to $300,000 every three years.

In addition to storm-induced damages to upland development, potential public safety issues associated with continued beach erosion also concern the city. Lack of beach in front of the railroad tracks and revetments along some sections of the shoreline does not allow safe passage for beach walkers during periods of high surf. These same narrow beaches impede lifeguard response to emergencies. Additionally, a danger is posed to swimmers by hard substrate and man-made structures, which have been exposed by the ongoing sand losses.

Plate 5.8 Railroad right-of-way fronted by narrow San Clemente beaches, June 2001

Planned Project

A portion of the non-federal cost of a Corps Feasibility Study would be supported by the PBRP grant. The goal of the study is to identify methods to accomplish the following specific objectives (USACE, 2000c):

1.) Enhance recreational opportunities;

2.) Protect the railroad corridor; and

3.) Reduce coastal storm damages to public facilities.

Beach nourishment is the favored alternative for addressing the erosion problem. The method would provide both recreational opportunities and storm protection. However, it is the most costly option. Offshore borrow sites would be dredged to acquire the necessary beach fill material. Sand retention devices, designed to prolong the effectiveness of a beach fill, would be considered as part of the nourishment option.

The total cost of the feasibility study was estimated to be $1.7 million. A 2½-year study period is anticipated. Data collection efforts in support of the project commenced in Fall 2001.

5.2.12 SANDAG Regional Beach Sand Project, San Diego County

Grant Recipient: San Diego Association of Governments (SANDAG)
Grant Amount: $1,236,500
Project Type: Beach Nourishment

Background

The coast of San Diego County extends from Orange County in the north to the Mexican Border in the south. Two complete littoral cells and the majority of a third cell are encompassed in this 76-mile stretch: the Oceanside Cell in the northern portion, the Mission Bay Cell in the central portion, and the Silver Strand Cell in the southern portion.

The county's beaches were severely eroded during the El-Niño winter of 1982-83, resulting in extensive damage to coastal facilities (Flick, 1993). To address the growing awareness of chronic erosion in many areas, the Coast of California Storm and Tidal Waves Study for the San Diego Region (CCSTWS-SD) was conducted by the Corps from 1983 through 1991 (USACE, 1991). The study identified two stretches of shoreline as sites of critical erosion: (1) the southern half of the Oceanside Cell (from Oceanside Harbor to La Jolla), and (2) the southern half of the Silver Strand Cell (from Imperial Beach to the Mexican Border).

In 1993, the San Diego Association of Governments (SANDAG) adopted a comprehensive plan for erosion mitigation known as the "Shoreline Preservation Strategy for the San Diego Region." The Strategy proposes an extensive beach-building and maintenance program to improve environmental quality, recreation, and storm protection in the coastal zone. A number of relatively modest "opportunistic" beach replenishment projects were undertaken prior to the planned project.

A more ambitious regional beach nourishment project was planned and partially executed as part of the U.S. Navy's Homeporting Project at North Island. To accommodate aircraft carriers, the U.S. Navy conducted major dredging operations in berthing areas and the San Diego Harbor entrance channel. Approximately 7 million cubic yards of sand dredged from these locations were intended to nourish the San Diego County shoreline through beach and nearshore placement. Sand was placed on the beaches of Mission Bay, Del Mar and Oceanside in September 1997; however, munitions were discovered in the sediment and nourishment operations ceased. Removing the munitions from the sand was deemed unfeasible, and the remaining dredged material was transported to the LA-5 deep-water disposal site. Subsequently, the Navy agreed to provide funds for beach nourishment in San Diego County.

Planned Project

Following the failed attempt to restore the shoreline using sand from the Navy homeporting project, the SANDAG Regional Beach Sand Project was initiated (SANDAG, 2000). The PBRP grant provided partial funding for the $17.5 million project. Viewed as the initial step in a long-term effort to restore the beaches, the project was the first regional beach nourishment effort on the West Coast. Recreational enhancement was a primary motive for conducting the project, in light of the substantial economic benefits provided to the region by beach tourism (Chapter 3, this report).

Over two million cubic yards of sand were placed on 12 San Diego area beaches, encompassing six miles of coastline, between April and September 2001. The sand was mined from five offshore borrow sites, using a hydraulic suction dredge, and then pumped onshore. Once onshore, the fill material was spread along the shoreline with earth moving equipment. Table 5.3 lists each site that was replenished, and the approximate nourishment quantities placed.

Table 5.3 San Diego Regional Beach Sand Project Nourishment Sites

Site	Nourishment Quantity (cubic yards)
Oceanside	380,000
North Carlsbad	240,000
South Carlsbad	160,000
Batiquitos, Encinitas	118,000
Leucadia State Beach, Encinitas	130,000
Moonlight State Beach, Encinitas	88,000
Cardiff State Beach, Encinitas	104,000
Fletcher Cove, Solana Beach	140,000
Del Mar	180,000
Torrey Pines State Beach, San Diego	240,000
Mission Beach, San Diego	100,000
Imperial Beach	120,000
Total	***2,000,000***

Source: SANDAG, 2000

Plates 5.9 and 5.10 show the North Carlsbad site before nourishment operations and after 240,000 cubic yards of sand were placed on the beach.

Plate 5.9 Pre-nourishment condition at North Carlsbad site, April 2001

Plate 5.10 Post-nourishment condition at North Carlsbad site, November 2001
(arrows point to approximately the same location on each photo)

A monitoring plan was implemented to determine the fate of the nourishment material. The effort is three-fold, and includes the following primary components:

- Monthly Beach Width Measurements: Obtained by city lifeguards to document short-term shoreline changes.
- Semi-Annual Beach Profile Surveys: To monitor long-term changes of the beach and nearshore zone.
- Semi-Annual Topographic Measurements at Lagoons: To document any impact of nourishment on tidal flow through lagoon inlets.

5.2.13 Feasibility Study at Encinitas and Solana Beach, San Diego County

Grant Recipient:	City of Encinitas and City of Solana Beach
Grant Amount:	$800,000 ($400,000 awarded to each city)
Project Type:	Corps of Engineers Feasibility Study

Background

Narrow sand or cobble beaches fronting unconsolidated bluffs characterize the Encinitas and Solana Beach shoreline. During winter months, beaches may be nonexistent along critical sections of the coast (Plate 5.11). Cardiff, a low-lying area backed by the San Elijo Lagoon, is situated between the bluffs of Encinitas and Solana Beach. In recent years, this stretch of coast has exhibited a narrow cobble berm with little or no sandy beach. Storm damage is common along both the bluff-backed and low-lying stretches of coast, and is attributable to narrow or nonexistent beaches.

Ongoing beach and bluff erosion in Encinitas and Solana Beach threatens public and private development. The primary erosion mechanism is wave undercutting at the base of the seacliff, which leads to instability and catastrophic failure of the upper bluff. Over 90 bluffs failures were reported between 1990 and 2000 (USACE, 2000d). Bluff failures also constitute a significant public safety issue, as evidenced by a January 2000 fatality resulting from a bluff collapse.

Storm-related damages along the Cardiff shoreline are typically associated with coastal flooding and road closures. Area restaurants and businesses spend an estimated $11,000 per storm event on temporary flood prevention measures. Between 1988 and 2000, the Pacific Coast Highway was closed on nearly 50 occasions due to dangers associated with wave overwash and cobbles thrown onto the roadway by stormy seas (USACE, 2000d). In addition to maintenance costs, road closures impact the livelihood of local businesses.

The region's chronically-narrow beaches currently do not provide the protective capacity needed to prevent bluff erosion and coastal flooding. A 1996 U.S. Army Corps of Engineers study found that over 100 bluff-top structures along the most critically-eroded section of the Encinitas shoreline would be threatened within the next 50 years if erosion mitigation measures are not implemented (USACE, 1996). The frequency of highway closures and coastal flooding events in the Cardiff area also are likely to increase without some form of beach restoration.

In addition, beach widths are not adequate to support the current recreational demand. Beach nourishment operations conducted within the reach by SANDAG in summer 2001 created wider recreational beaches and provided temporary protection for portions of the coast.

Plate 5.11 Narrow beaches backed by seacliffs in Encinitas, May 1999

Planned Project

The cities of Encinitas and Solana Beach contracted with the Corps to conduct a feasibility study for restoring the shoreline. A $3.1 million budget was established for the study. The specific objectives of the study are (USACE, 2000d):

1) Restore recreational value of the region's beaches;
2) Mitigate hazardous conditions associated with bluff failures;
3) Prevent Pacific Coast Highway closures during storm events;
4) Protect and enhance the San Elijo Lagoon; and
5) Reduce coastal storm damage to public and private development.

Beach nourishment and managed retreat are among the alternatives being considered in the project. Sand nourishment will help prevent storm damages and generate recreational opportunities by creating a wider beach. In addition, public safety will be improved by reducing bluff collapses. Offshore borrow sites in the area, utilized by the SANDAG Regional Beach Sand Project, would be used to acquire the necessary nourishment material. To prolong the effectiveness of a beach fill, sand retention devices will be considered as part of the nourishment option.

Managed retreat would involve a buyout of residences at risk from bluff failures. Upon establishing an appropriate set-back distance, the properties would be transformed into public open space. This alternative provides the added benefit of modest sediment supply to the beach through continued seacliff erosion (Chapter 8, this report). However, beach recreation and public safety issues related to bluff failures are not directly addressed by this alternative.

5.2.14 Feasibility Study at Imperial Beach, San Diego County

Grant Recipient:	City of Imperial Beach
Grant Amount:	$200,000
Project Type:	Corps of Engineers Feasibility Study

Background

Imperial Beach, the southernmost coastal community in California, spans 1.5 miles of shoreline in San Diego County. The beaches are backed by homes, public facilities, and coastal wetlands.

In contrast to most California regions, the predominant direction of sediment transport along Imperial Beach is south-to-north (USACE, 1986a). This may be attributed to the sheltering effects of Point Loma. The Tijuana River is the primary natural source of sediment to the beaches. Flood control measures, constructed on both sides of the international border since 1938, have significantly reduced the amount of sand delivered to the coast. The relict Tijuana River delta is a prominent feature at the south end of the city shoreline (Plate 5.12).

Plate 5.12 Imperial Beach shoreline, April 2001

The primary contributors to erosion at Imperial Beach are reduced sediment yield from the Tijuana River, erosion of the relict delta, and human encroachment (DBW, 1994). The sand beaches are typically narrow, and often are nonexistent at areas south of the pier. Shoreline recession rates of 1-2 feet per year have been estimated. Seawalls and revetments have been constructed to protect development at several locations, and groins have been utilized to stabilize the shoreline north of the pier.

Over 34 million cubic yards of sand, derived from construction and dredging in San Diego Harbor, have been utilized to nourish the shoreline south of Point Loma (Flick, 1993). The majority of the material was placed north of Imperial Beach in the mid-1940's. As a result, the Coronado and Silver Strand beaches received the greatest benefits. More recently, dredged material from harbor construction has been transported to Imperial Beach and deposited in nearshore bars, including 233,000 cubic yards dredged from the U.S. Navy Pier 2 in 1997 (SANDAG, 2000). This material migrated shoreward during Summer 1998, increasing the beach width immediately south of the pier.

Planned Project

A Corps feasibility study is planned to identify solutions to erosion problems at Imperial Beach. A portion of the non-federal contribution required to conduct the study will be provided by the PBRP grant.

The objective of the study is to evaluate measures to reduce storm damage along the Silver Strand and Imperial Beach shoreline. Sand replenishment is the primary option for beach restoration. The two alternatives under consideration are (Risko, 2001):

- Alternative 1 – Beach Fill with Periodic Re-Nourishment
- Alternative 2 – Beach Fill with Nearshore Berm and Periodic Re-Nourishment

Re-nourishment cycles under Alternative 1 range from 11 to 50 years. Alternative 2 specifies a re-nourishment interval of 10 years. The estimated study cost is $1.4 million, and will be conducted on a 65% federal and 35% non-federal cost sharing basis.

5.2.15 Southern California Beach Processes Study

Grant Recipient:	Scripps Institute of Oceanography
Grant Amount:	$500,000
Project Type:	Coastal Processes Study

Background

Upon completion of a beach nourishment project, waves and currents redistribute the sand both offshore and alongshore. To predict the evolution of a beach fill, and hence its performance, scientists and engineers typically rely on computer models. The quality of the predictions is a function of the underlying physics of the model, the input wave conditions, site-specific calibrations, and the experience of the scientist or engineer.

The computer models commonly used for beach nourishment design in California were originally developed for East Coast environments. Little research has been done to assess the limitations of these models when applied to the more energetic wave environment and complex coastline in California. A better understanding of these limitations can allow for more realistic beach fill designs.

Planned Project

The PBRP grant funds a portion of the *Southern California Beach Processes Study*. The remainder of the $1 million study is supported by the State of California Resources Agency and the Department of Finance.

The primary objective of the study is to improve the technical basis for beach nourishment design in California. Both wave transformation and beach evolution models will be investigated. A better knowledge of the limitations and capabilities of the available models will promote more effective designs, which will increase the performance and economic viability of projects.

The study will utilize the SANDAG-sponsored beach fill at Torrey Pines as a field laboratory. The project will be monitored extensively over a two-year period. The following tasks will be undertaken:

- *Task 1:* Conduct high-resolution surveys to document the evolution of the Torrey Pines beach fill;
- *Task 2:* Collect wave height and direction data at the Torrey Pines site;
- *Task 3:* Enhance existing wave transformation models to provide improved input data for beach evolution models; and
- *Task 4:* Evaluate the GENESIS and SBEACH numerical models using the wave and beach evolution data obtained in Tasks 1 and 2.

The data collected during the study will be made available on the internet. Scientists and engineers throughout the world will have the opportunity to utilize the high-quality data to study beach fill evolution and sand transport processes.

The results of the study will be documented in a series of reports submitted to the Resources Agency and the DBW. Results will be disseminated to the scientific community through technical journals and conference papers.

Data collection efforts began in Spring 2001, prior to the commencement of beach nourishment operations at the Torrey Pines site.

5.3 Future Needs

The economic value of California's beaches to the national, state, regional and local economies is demonstrated in Chapter 3 of this report. The passage of Assembly Bill 64 in 1999 and the subsequent creation of the PBRP emphasized the need to allocate appropriate financial resources for the nourishment of the state's beaches. In 2000, the DBW conducted a statewide inventory of beach erosion hot spots to identify sites in need of restoration and subsequently estimated the volume of sand necessary to successfully mitigate the erosion problems at each beach.

Table 5.4 lists both the candidate sites identified in the DBW's inventory and the feasibility studies funded by the PBRP in fiscal year (FY) 2000-01, as the beaches that will be analyzed as part of these current feasibility studies also are sites that require beach nourishment. The initial volume listed in the table for each site is based on a minimum berm width of 100 feet throughout the project length (or an equivalent volume of about 100 yd^3 of sand per lineal foot of project length). For the current feasibility projects, the estimated project lengths and sediment volumes are presented in the table.

Table 5.4 Future California Beach Nourishment Requirements

Current Project Commitment	Beach Nourishment Sites		Project Length (ft)	Initial Volume (yd^3) *
	County	Location		
Potential Projects	San Francisco	Ocean Beach	250	8,000
	Alameda	Crown Beach	1,000	100,000
	San Mateo	Coyote Point	2,400	240,000
	Santa Barbara	Refugio State Beach	2,000	200,000
	Santa Barbara	El Capitan State Beach	2,000	200,000
	Santa Barbara	Goleta State Beach	4,000	400,000
	Santa Barbara	Carpinteria State Beach	2,500	250,000
	Ventura	La Conchita	9,000	900,000
	Ventura	Hobson County Park	9,000	900,000
	Ventura	Emma Wood County Beach	7,000	700,000
	Ventura	Pierpont Beach	1,200	120,000
	Los Angeles	Dan Blocker Beach	3,500	350,000
	San Diego	Carlsbad State Beach	15,000	1,500,000
	San Diego	San Diego State Beaches **	8,000	800,000
	San Diego	Mission Beach	2,500	250,000
		Subtotal=	69,350	6,918,000
FY 2000-01 Feasibility Studies ***	Santa Barbara	Carpinteria City Beach	1,500	150,000
	Los Angeles	Peninsula Beach	2,500	250,000
	Orange	Seal Beach	4,000	400,000
	Orange	Huntington Cliffs	4,600	460,000
	Orange	San. Clemente	4,500	450,000
	San Diego	Oceanside	15,000	1,500,000
	San Diego	Encinitas	10,000	1,000,000
	San Diego	Solana Beach	5,280	528,000
	San Diego	Imperial Beach	8,000	800,000
		Subtotal=	55,380	5,538,000
		TOTAL=	**124,730**	**12,456,000**

* All nourishment volumes are designed to supply 100 yd^3/ft of sand (or an equivalent 100-ft berm width over the project length)

** San Diego State Beaches include Batiquitos, Leucadia, Cardiff, and Torrey Pines

*** Estimated lengths and volumes were employed for currently authorized feasibility studies

To calculate the funds required to conduct a successful beach nourishment program throughout the state, the design and construction costs of the projects listed in Table 5.4 were estimated. These estimates and estimates of future maintenance costs are presented in Table 5.5.

Table 5.5 Potential Beach Restoration Costs
(In thousands of dollars)

Project Locations	Total Initial Project Cost *	Federal Share of Initial Cost	State Share of Initial Cost	Total Annual Cost ***	State Share of Annualized Maintenance Cost
Potential Projects					
Ocean Beach **	$0	$0	$0	$450	$225
Crown Beach	$1,300	$845	$455	$260	$130
Coyote Point	$2,560	$1,664	$896	$512	$256
Refugio State Beach	$2,200	$1,430	$770	$440	$220
El Capitan State Beach	$2,200	$1,430	$770	$440	$220
Goleta County Beach	$2,800	$1,820	$980	$560	$280
Carpinteria State Beach	$2,650	$1,723	$927	$530	$265
La Conchita	$8,500	$5,525	$2,975	$1,700	$850
Hobson County Park	$8,500	$5,525	$2,975	$1,700	$850
Emma Wood County Beach	$6,700	$4,355	$2,345	$1,340	$670
Pierpont Beach	$1,480	$962	$518	$296	$148
Dan Blocker Beach	$3,550	$2,308	$1,242	$710	$355
Carlsbad State Beach	$13,900	$9,035	$4,865	$2,780	$1,390
San Diego State Beaches	$7,600	$4,940	$2,660	$1,520	$760
Mission Beach	$2,650	1,723	$927	$265	$133
Subtotal=	$66,590	$43,285	$23,305	$13,503	$6,752
FY 2000-01 PBRP Nourishment Projects					
Surfside-Sunset Beach **	$0	$0	$0	$2,600	$1,300
Subtotal=	$0	$0	$0	$2,600	$1,300
FY 2000-01 PBRP Feasibility Studies					
Carpinteria City Beach	$1,750	$1,138	$612	$350	$175
Peninsula Beach	$2,650	$1,723	$927	$530	$265
Seal Beach	$4,000	$2,600	$1,400	$800	$400
Huntington Cliffs	$4,540	$2,951	$1,589	$908	$454
San Clemente	$4,450	$2,893	$1,557	$890	$445
Oceanside	$13,900	$9,035	$4,865	$2,780	$1,390
Encinitas	$9,400	$6,110	$3,290	$1,880	$940
Solana Beach	$5,152	$3,349	$1,803	$1,030	$515
Imperial Beach	$7,600	$4,940	$2,660	$1,520	$760
Subtotal=	$53,442	$34,739	$18,703	$10,688	$5,344
TOTAL=	**$120,032**	$78,024	**$42,008**	$26,791	**$13,396**

* For all projects not funded currently, costs of $7.50/yd^3 for sand, $400,000 for Design and Construction and 20% contingency have been used. The actual estimated renourishment and construction costs were employed for the currently authorized Surfside-Sunset Beach ongoing nourishment project. No monetary adjustments have been performed for future dollars

** Indicates a 2000-01 PBRP nourishment project for which initial funds have been appropriated already

*** A 5-year replenishment interval has been employed (except for Ocean Beach)

Note: All costs are estimates and are subject to change.

The initial project costs were calculated based on a unit cost of $7.50 per cubic yard. Estimates include engineering design and construction administration costs of $400,000 and a 20%

contingency. To determine the annual cost of maintaining the design integrity of each project, a 5-year renourishment interval was applied to each project, except for Ocean Beach in San Francisco, which is to be nourished before every winter season. It should be noted that beach nourishment projects that are properly renourished at regular intervals with beach-quality material typically require smaller volumes of sand over time to sustain their initial design. If the beaches listed in Table 6.5 are properly maintained, the annual renourishment costs may decrease with time.

Under federal law (Water Resources Development Act of 1986, Section 103; Water Resources Development Act of 1999, Section 218), the non-federal partner is required to pay 35% of the initial implementation cost and 50% of maintenance costs for each project that is cost-shared with the federal government through the Army Corps of Engineers. Accordingly, the state will be required to pay for half of the recurring beach maintenance costs during subsequent renourishment cycles. Table 5.5 lists the state share of the potential initial and annual costs for each project in addition to the total costs. Note that the initial costs for the FY 2000-01 PBRP nourishment projects are not included in the overall totals as they are funded already. To initiate each of the potential projects listed in Table 5.5 not currently funded by the PBRP, the total state and federal cost would be approximately $120 million. Subsequent annual renourishment costs to maintain the initial investment are estimated to be approximately $26.8 million. If the costs of each project were shared with the federal government, then the state's portion would be only $42 million for the initial project costs with a subsequent annual maintenance cost of approximately $13.4 million.

Table 5.5 clearly demonstrates both the commitment that will be required by California in order to restore and maintain its valuable beach resources and the savings that can be expected by aggressively pursuing partnerships with the Corps on beach nourishment projects that provide significant benefits for both the state and federal governments.

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6. EFFECTIVENESS OF THE PROGRAM

Because the nourishment projects funded through the Public Beach Restoration Program are in the early stages of implementation, an evaluation of their effectiveness is premature. Judging from the success of prior nourishment projects, however, the current projects offer the potential for significant improvement of the state's beaches. To provide insight into the results achieved in the past, the sections that follow provide an overview of historical beach nourishment activities in the state, followed by an in-depth review of specific projects.

6.1 Overview

Beach nourishment has been conducted in California for most of the past century. Although we are inclined to regard the wide, sandy beaches of cities like Santa Monica, Venice, Newport Beach, and Mission Bay as part of the state's "natural" endowment, they were in fact created by nourishment programs that commenced as early as the 1920's. The pre-nourishment condition was distinctly different -- typically a narrow strip of dry beach on a sand-starved coast -- and totally incapable of accommodating the present-day demands for coastal access and recreation. Other benefits that accrue from past nourishment projects, in addition to coastal access and recreation, include enhanced public health and safety, restored wildlife habitats, increased protection for upland facilities against winter storm waves, and a significant revenue stream from coastal tourism.

The nature of beach nourishment has evolved as planners, scientists, and engineers have gained more knowledge of the coastal environment. Whereas structural means of shoreline stabilization (such as groins and detached breakwaters) were common 30 to 50 years ago, beach nourishment has emerged as the preferred method in recent decades. However, nourishment has long been recognized as a viable means of beach restoration in California (Wiegel, 1994). In a 1952 study of the California coast between Point Mugu and San Pedro, the U.S. Army Corps of Engineers Erosion Board drew the following conclusion (US Congress, 1953):

> *"Where conditions permit, probably the best means of protecting a beach or a shoreline against erosion of any type is to introduce a sandfill between the shoreline to be protected and the ocean and maintain that protective fill against long-term erosion."*

Numerous past projects have been associated with harbor construction, while others were undertaken to protect upland developments such as public and private structures, or transportation corridors such as the Pacific Coast Highway and railway links. Most projects can be segregated into two general categories:

1.) Deterministic Nourishment – Deterministic beach nourishment projects are those that are undertaken for the primary purpose of putting sand on beaches. Typical motivations for such projects include mitigating the adverse effects of nearshore and beach structures and compensating for the reduction in natural sediment supply from rivers and streams caused by dams and debris basins.

2.) Opportunistic Nourishment – Opportunistic beach nourishment projects are those that are undertaken when beach-quality sand becomes available from projects unrelated to beach nourishment. To date, the primary sources of this "sand of opportunity" in California have been harbor construction and maintenance dredging. Opportunistic nourishment is driven by economics, in that it often proves more cost effective to place the excavated material on nearby beaches than to dispose of it inland or offshore.

The following sections describe representative deterministic and opportunistic beach nourishment projects that have been conducted along the California coast.

6.2 Deterministic Beach Nourishment Projects

As indicated previously, nourishment projects planned and executed for the express purpose of beach restoration or maintenance can be categorized as deterministic. These projects range from large-scale regional beach nourishment programs to local erosion-control efforts.

6.2.1 Planned Regional Beach Nourishment in Orange County

The Orange County Beach Erosion Control Project was initiated by the U.S. Army Corps of Engineers, in concert with the State of California and the County of Orange, in 1964. The general objective of this regional beach nourishment program is to mitigate erosion along the Orange County shoreline between Surfside-Sunset Beach and Newport Harbor caused by extensive coastal and upland development during the early part of the 20th century. The project consists primarily of ongoing periodic beach nourishment at Surfside-Sunset Beach, and beach nourishment in conjunction with sand containment devices at West Newport Beach.

The Orange County project is a representative model for large-scale beach replenishment programs for other regions in California. The SANDAG Regional Sand Project, for example, involved the placement of 2 million cubic yards of material along the San Diego County coastline. A similar program is currently being planned by BEACON for Santa Barbara and Ventura Counties. A central component of each program is the utilization of offshore borrow sources for beach nourishment.

Project History

Historically, sand was delivered naturally to the beaches of northern Orange County by the San Gabriel and Santa Ana Rivers, with modest input from coastal bluff erosion in the Huntington Beach area. Following construction of flood control measures on these rivers, the jetties at Anaheim Bay (for the U.S. Naval Weapons Station, Seal Beach) and the breakwaters of the Long Beach – Los Angeles Harbor Complex, significant changes occurred to the natural condition of the region. These changes include a reduction in the volume of sediment reaching the coast, modification of the wave energy available to move sand alongshore, impediments to sediment movement at major coastal barriers, and reversed sediment transport direction along certain segments of the coast. Some beaches benefited from these changed conditions, while others did not. Beach erosion was particularly severe in front of the communities of Surfside-Sunset Beach and West Newport Beach, where wave action has caused coastal flooding and property losses (USACE, 1999).

The chronic erosion problem at Surfside-Sunset Beach (Plate 6.1) became apparent soon after completion of the Naval Weapons Station in 1944. To provide protection for homes along the eroding beach, a revetment was built by the Navy in 1945 and most recently refurbished in the 1990's. The first beach nourishment operations also were conducted in 1945. Between 1945 and 1956, nearly 2.3 million cubic yards of material dredged from the Naval Weapons Station were used to replenish the eroding Surfside-Sunset shoreline (Shaw, 1980).

Plate 6.1 Surfside-Sunset Beach, November 2000

A 1962 U. S. Army Corps of Engineers cooperative study identified a significant need for beach restoration in the region (USACE, 1962). As a result, the Corps, in concert with the State of California and the County of Orange, initiated the Orange County Erosion Control Project in 1964. A primary component of the project is periodic and ongoing nourishment at Surfside-Sunset. The beach fills provide temporary protection for Surfside-Sunset, and also serve to nourish downcoast beaches as waves and currents move the sand alongshore towards Newport Beach.

To mitigate erosion at West Newport Beach, the project plan included beach nourishment and construction of sand retention devices. The shoreline stabilization measures were designed to minimize the loss of nourishment material and increase the intervals between beach fills. Only limited re-nourishment has been required since the initial beach fills and sand retention devices were constructed in the 1960's and 1970's.

The project was designed to be constructed in stages. The work pertaining to Stages 1, 4A, 7, 8, 9,10, and 11 of the project was located in the Surfside-Sunset Beach area and Stages 2, 3, 4B and 5 were located in West Newport Beach. Stage 6 never took place. A more detailed summary of each stage is provided in Table 6.1.

Project Performance

Northern Orange County beaches currently are wider and contain greater volumes of sand than existed prior to the initiation of the Orange County Beach Erosion Control Project. Beach nourishment has enhanced recreational opportunities, improved coastal access, and increased coastal protection while reducing the need for hard structural armoring. The beaches attract millions of visitors each year, providing sustainable economic benefits.

Beach width and sand volume changes provide a relatively objective measure of the effectiveness of the Orange County Beach Erosion Control Project. As part of the Coast of California Storm and Tidal Waves Study for the Orange County Coast (CCSTWS-OC), these tools were used to analyze the coastal changes in the region since the project was initiated. Salient findings from the study are discussed below (USACE, 1999).

Table 6.1 Orange County Beach Erosion Control Project Construction History

Date	Project Milestone	Beach Nourishment			Sand Retention Devices
		Quantity (cubic yards)	Placement Site	Borrow Site	
1964	Stage 1	4,000,000	Surfside-Sunset	Naval Weapons Station	---
1968	Stage 2	495,000	West Newport Beach	Santa Ana River & Balboa Peninsula	*Construction of Steel Sheetpile Groins* 40th, 44th St, and 48th Streets
1970	Stage 3	874,000	West Newport Beach	Santa Ana River	*Construction of Rubblemound Groins* 36th, 52nd, and 56th Streets *Rubble Encasement of Sheetpile Groin* 48th Street
1971	Stage 4A	2,300,000	Surfside-Sunset	Naval Weapons Station	---
1973	Stage 4B Stage 5	358,000	West Newport Beach	Santa Ana River	*Construction of Rubblemound Groins* 32nd and 28th Streets *Rubble Encasement of Sheetpile Groins* 40th and 44th Streets
Deferred	Stage 6	---	---	---	Proposed an offshore breakwater and south jetty extension at Santa Ana River. ***Deferred pending a demonstrated need***.
1979	Stage 7	1,600,000	Surfside-Sunset	Nearshore Borrow Pits	---
1985	Stage 8	2,700,000	Surfside-Sunset	Nearshore Borrow Pits/ Naval Weapons Station	---
1990	Stage9	1,800,000	Surfside-Sunset	Nearshore Borrow Pits	---
1997	Stage 10	1,600,000	Surfside-Sunset	Nearshore Borrow Pits	---
2001	Stage 11	1,800,000	Surfside-Sunset	Nearshore Borrow Pits	---

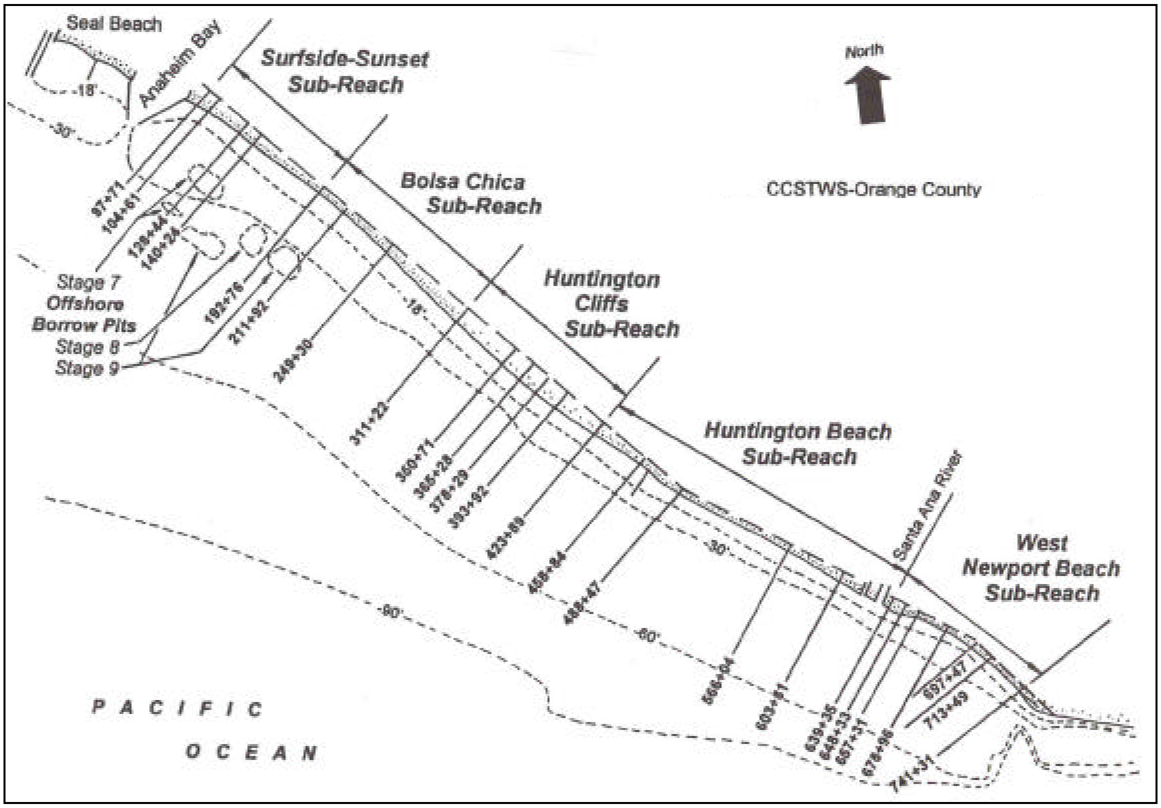


Figure 6.1 CCSTWS-Orange County study area with beach profile locations

To facilitate a discussion of these coastal changes, the study area was divided into five sub-reaches. The sub-reaches are shown in Figure 6.1 and characterized below.

- *Surfside-Sunset:* Adjacent to Anaheim Bay (Naval Weapons Station). Serves as a "feeder" beach and has received nearly 14 million cubic yards of nourishment material since 1963.
- *Bolsa Chica*: Contains wide, sandy beaches backed by a lowland marsh.
- *Huntington Cliffs:* Comprised of narrow beaches backed over much of its length by high coastal bluffs.
- *Huntington Beach:* Contains wide, sandy beaches. Coastal structures include the Huntington Beach Pier and the Santa Ana River Jetties.
- *West Newport Beach:* Consists of wide, stable beaches. Modified extensively by armor and beach nourishment. Coastal structures include a groin field and the Newport Pier.

The mean sea level (MSL) beach width is a measure of the above-water portion of the beach, and provides an indication of the protective capacity of the beach as well as the amount of dry sand available for recreation. Figure 6.2 shows the average MSL beach width for each sub-reach over the 34-year period between 1963 and 1997.

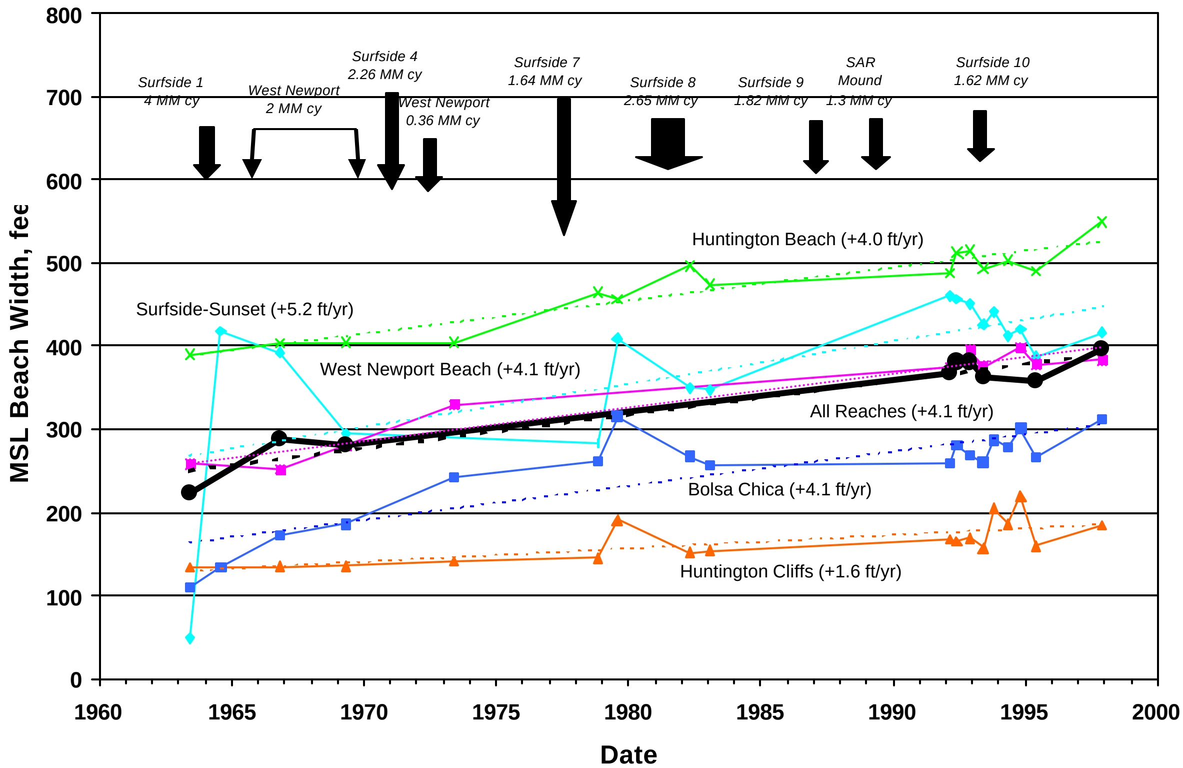


Figure 6.2 Average MSL beach width by sub-reach

Since the project was implemented, beach widths have increased in all sub-reaches. The rates of shoreline advance range from +1.6 ft/year at Huntington Cliffs to +5.2 ft/year at Surfside-Sunset. Over the entire study area, beach widths have increased at an average rate of +4.1 ft/year. The substantial fluctuations in beach width evident at the Surfside-Sunset sub-reach reflect the effects of periodic beach nourishment interspersed by periods of erosion.

Comparisons of the accumulated volume of sand in the nearshore region between Anaheim Bay and the Santa Ana River with the volume of nourishment material placed at Surfside-Sunset are shown in Figure 6.3. The nearshore volumes are representative of the material contained in the active littoral system. This includes not only the above-water beach, but also sand located in the nearshore waters that moves seasonally onshore and offshore.

When the accumulation of nearshore sediment volume is compared with the quantity of beach-quality sediment supplied at Surfside-Sunset, the agreement is found to be remarkably close.

This indicates that most of the nourishment material placed at Surfside-Sunset is still in the active littoral system and benefiting the region's beaches.

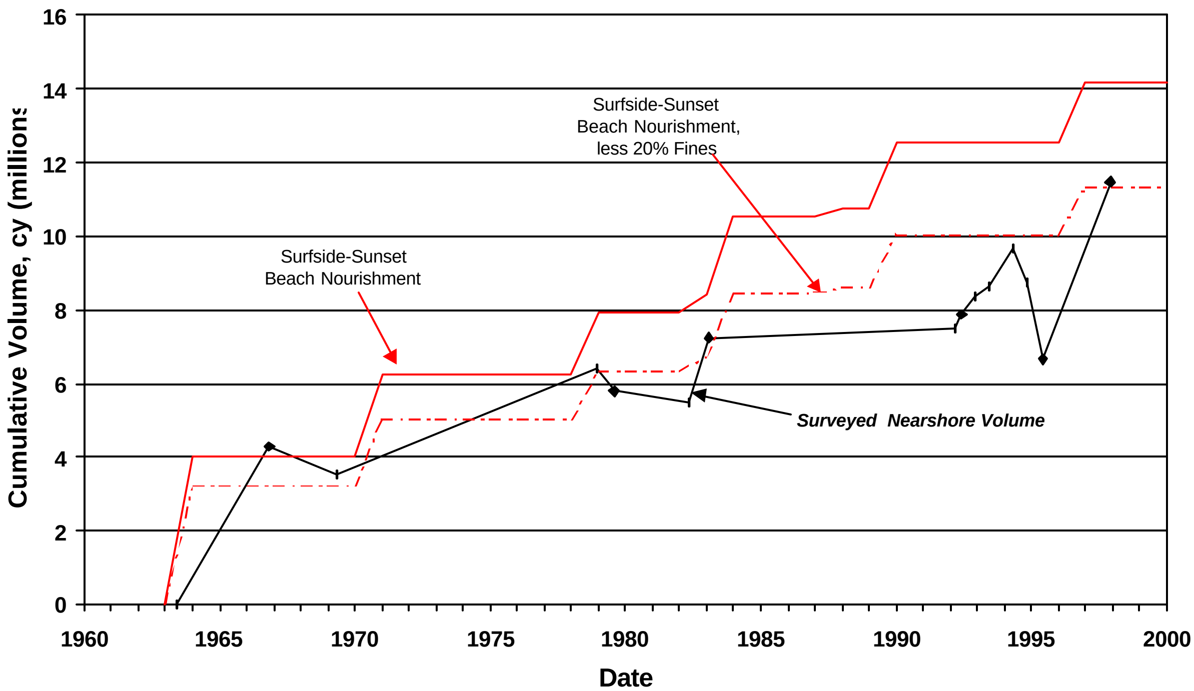


Figure 6.3 Comparison of surveyed nearshore volume with nourishment volume

The magnitude of the shoreline changes can be further illustrated by comparison of historical photographs. Plates 6.2 and 6.3 show Huntington Beach, near the municipal pier, in 1931 and 1986. The West Newport Beach shoreline in 1934 and 1992 is shown in Plates 6.4 and 6.5, respectively. The current beach is wider at both locations when compared to historical conditions.

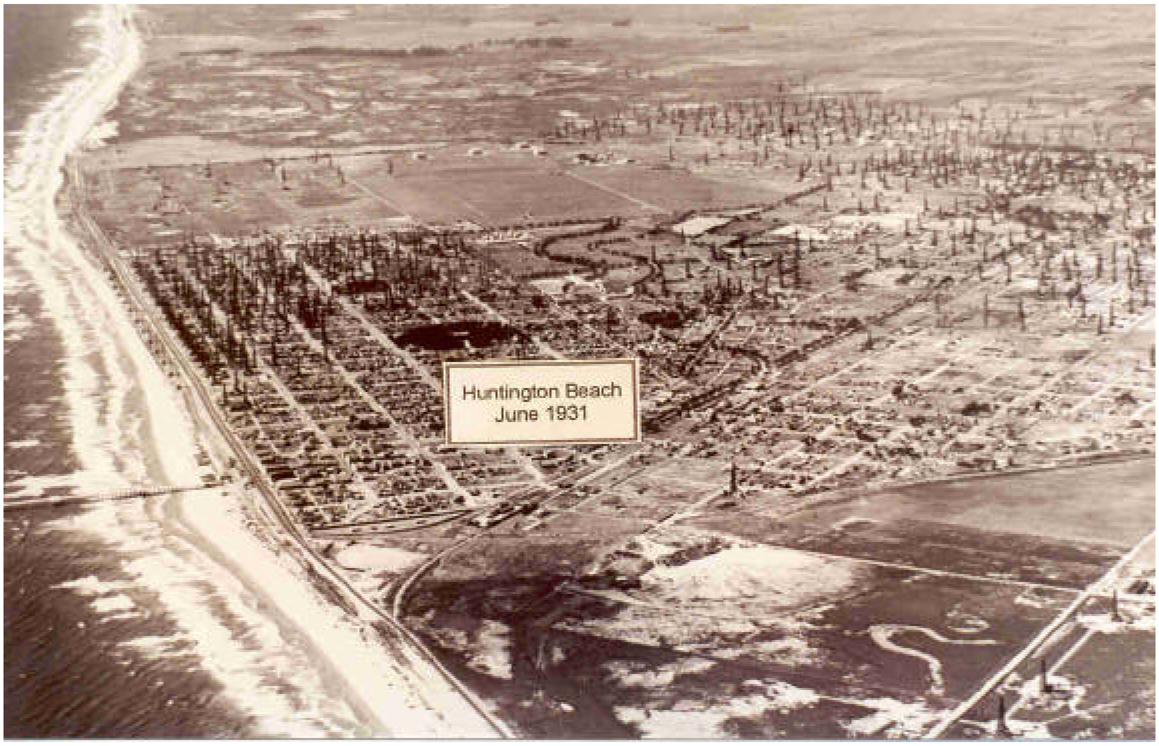


Plate 6.2 Huntington Beach, 1931 (looking northwest)

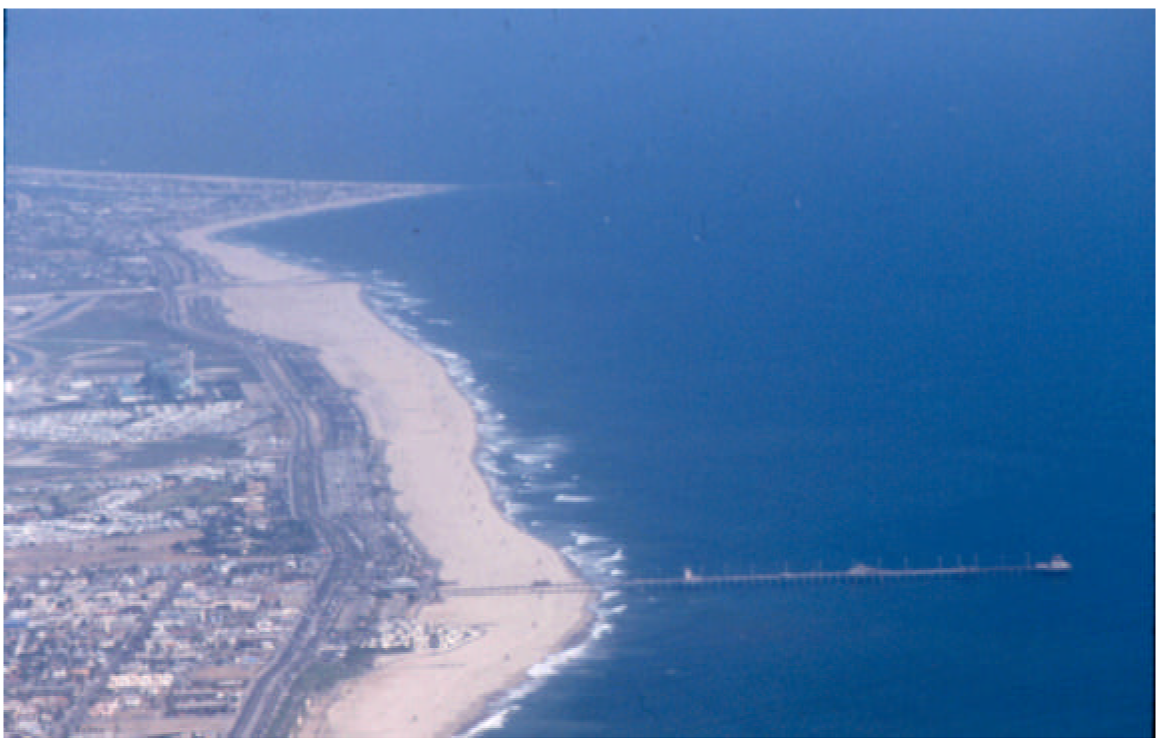


Plate 6.3 Huntington Beach, 1986 (looking southeast)

Plate 6.4 West Newport Beach, 1934 (looking southeast)

Plate 6.5 West Newport Beach, 1992 (looking south)

6.2.2 Sand Backpassing at Peninsula Beach, Long Beach

The City of Long Beach has conducted sand backpassing operations to nourish Peninsula Beach since 1994. The primary objectives of the program are to maintain recreational beaches and provide storm protection along 2,500 ft of eroding shoreline. The nourishment method consists of "recycling" sand from a wide stable beach to a nearby sediment-starved beach. Unlike conventional beach nourishment methods, no new material is added to the littoral system.

The program performed at Peninsula Beach is representative of similar operations that have been conducted elsewhere along the California coast. Backpassing between East and West Beach in nearby Seal Beach has been performed periodically since the 1960's (Moffatt and Nichol, 1984). In Orange County, sand has been transported from the wide beaches of Balboa to West Newport on several occasions (USACE, 1993). Another example can be found in Santa Monica Bay, where sand was backpassed from Marina del Rey to Venice Beach in 1973 (Leidersdorf et al., 1994).

Project History

Peninsula Beach, at the eastern end of Long Beach, has suffered chronic erosion for several years. The Long Beach breakwater protects the majority of the City's beaches from storm wave impacts; however, at the eastern end of the structure, waves proceed unimpeded to Peninsula Beach. The typical pattern of shoreline change consists of erosion and alongshore transport from Peninsula Beach to the sheltered beaches in the lee of the breakwater (Figure 6.4).

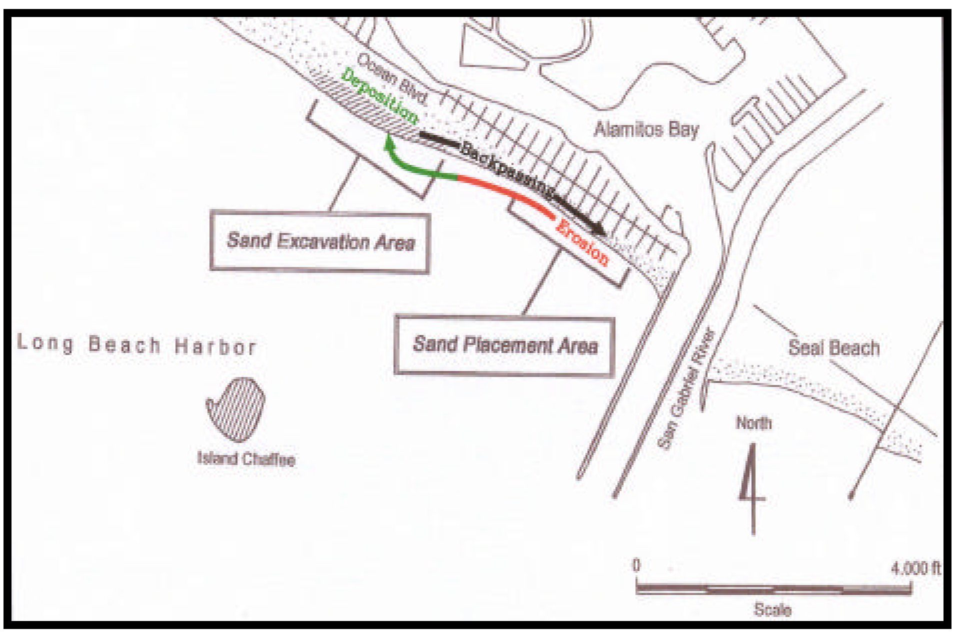


Figure 6.4 Peninsula Beach backpassing operation

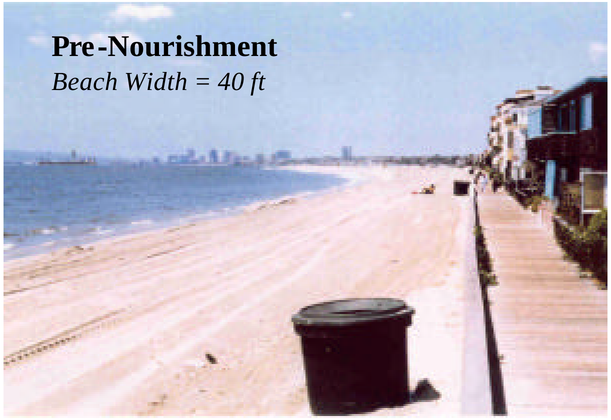
Several investigations have been conducted to develop solutions to the recurring erosion problem. Structural means of protection are often burdened by high capital costs, environmental concerns, and public opposition. As a result, the City Council adopted the sand backpassing program in 1994 to address beach erosion at Peninsula Beach. The operation, shown schematically in Figure 6.4, utilizes large land excavation "scrapers" to collect sand from the borrow site located to the west and transfer the material to the eroding shoreline at Peninsula Beach to the east. Haul distances are typically less than 2 miles. Plate 6.6 shows the operation in progress.

Plate 6.6 Sand backpassing at Peninsula Beach, November 1994

Operations have been conducted on 9 occasions since November 1994, with the most recent backpassing effort completed in March 2001. Nourishment volumes have ranged between 60,000 and 100,000 cubic yards.

Project Performance

The sand backpassing program implemented by the City of Long Beach has been highly effective in replenishing Peninsula Beach. Plate 6.7 provides a pre- and post-nourishment view of the beach. Like any maintenance operation, the success of the project is dependent upon re-nourishing before erosion subjects upland development to coastal storm damage. Re-nourishment has been required at intervals ranging from 3 to 18 months.



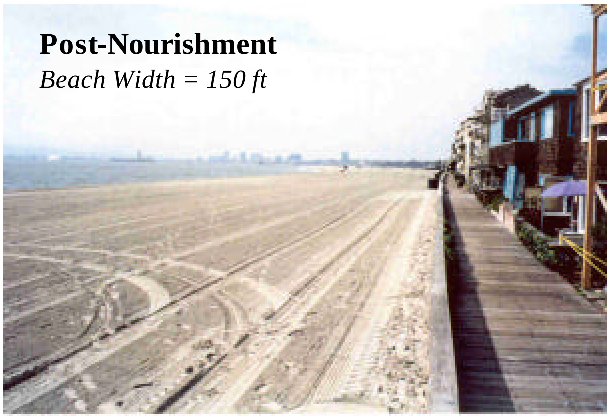


Plate 6.7 Pre- and post-nourishment condition near 65th Place (looking west)

The City conducts monthly beach width measurements to monitor the condition of the Peninsula Beach shoreline. When beach widths become critically narrow, typically 100 ft or less, the next backpassing episode is implemented. Figure 6.5 depicts the evolution of the nourished shoreline between 1994 and 2000. Eight backpassing operations were conducted during the period. The longevity of each nourishment episode is highly dependent on wave conditions at the site. Post-nourishment erosion rates varied from 0.3 ft/day to 3.8 ft/day.

Much of the program's success is due to the relatively modest construction costs. Because of the short transport distances, the average unit cost of the operation is typically less than $1.50 per cubic yard. In comparison, costs of beach nourishment operations involving inland sand sources typically range between $6 and $10/cy. Likewise, because hydraulic dredge operations are burdened by high mobilization charges, the unit cost of using that method for small nourishment programs is often in excess of $6/cy.

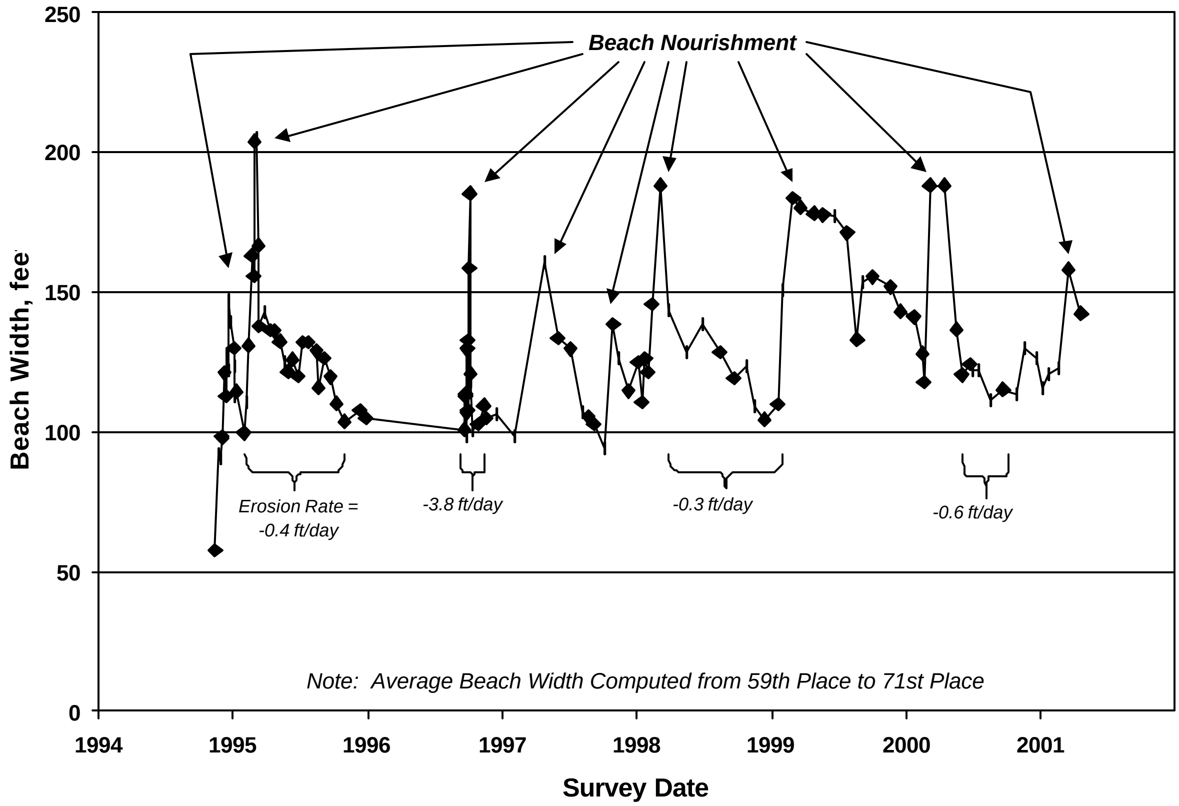


Figure 6.5 Beach width measured at Peninsula Beach, 1994-2001

6.2.3 Sand Bypassing at Santa Barbara Harbor

Sand bypassing has been conducted at Santa Barbara Harbor since 1933, longer than any other such operation in California. The nourishment method consists of transporting sand from the upcoast side of a sediment-blocking structure to the downdrift side to compensate for interrupting the natural downcoast flow of sand. The objective of the ongoing project at Santa Barbara is to maintain navigable depths within the harbor while providing beach sand for the downcoast shoreline.

Similar operations are conducted at most harbors along the coast that require periodic maintenance dredging. Examples include Santa Cruz Harbor in Northern California, and Ventura, Channel Islands/Pt. Hueneme, Marina del Rey, Oceanside, and Mission Bay in Southern California (Wiegel, 1994). Many of the harbors are designed with “sand traps” in an attempt to promote sediment accumulation in a controlled area and minimize shoaling in navigation channels. Most of the sand bypass operations conducted in California utilize mobile dredges to transport shoaled material from sand traps and harbor channels to the downcoast beaches.

Project History

Like the majority of ocean harbors in California, Santa Barbara Harbor was created by building large quarrystone structures in the nearshore zone. Construction of the facility began in 1927. The harbor was originally designed with a detached breakwater, which was intended to allow sand to pass along the shoreline relatively unimpeded. However, the harbor soon began to shoal, and the west end of the breakwater was connected to the shoreline in 1930.

East Beach, located immediately downdrift of the harbor, began to erode soon after completion of the breakwater. Shoreline recession of 500 ft to 600 ft was noted at some locations farther to the south (Peel in USACE, 1986). With the erosion problems progressing several miles downcoast, it became apparent that a sand bypassing program would be required to transport the sand that had accumulated at the harbor to the downcoast beaches. The first bypass operation was conducted in 1933, placing over 606,000 cubic yards of sand at East Beach. Since that time, bypassing has continued on a periodic basis, supplying downcoast nourishment material at an average annual rate of 350,000 cy/yr (Noble Consultants, 1989). Sand has been bypassed primarily from within the harbor and from a sand spit that forms off the eastern terminus of the breakwater.

Project Performance

Downcoast erosion was lessened following the implementation of the sand bypassing program at Santa Barbara Harbor. The shoreline advanced substantially at East Beach, which serves as the receiver site for the bypassed sand. Beach widths at this location have exceeded 300 ft during recent years (Hearon, 1997). East Beach and its amenities, including Stearns Wharf and a coastal path, are now valuable recreational and economic assets to Santa Barbara and surrounding communities.

Subsequent to nourishment, East Beach functions as a “feeder beach” as waves and currents transport the sand alongshore, nourishing the downcoast shoreline. The sand bypassed from the harbor has been sufficient to arrest severe erosion downcoast of East Beach; however, these beaches have never returned to pre-harbor conditions. The bypassing program essentially restored the littoral system to the pre-harbor status-quo, providing enough sand to avoid severe shoreline recession but insufficient quantities to rebuild the eroded beaches.

6.3 Opportunistic Beach Nourishment Projects

Opportunistic beach nourishment utilizes sand that was derived from projects whose primary motive was not beach replenishment. The majority of beach nourishment projects conducted in California have been opportunistic in nature. Projects have varied in size from a few thousand to several million cubic yards of material.

6.3.1 Opportunistic Nourishment in Santa Monica Bay

The majority of the wide, sandy beaches in Los Angeles County are directly attributable to beach nourishment. Most of the beach nourishment material has been "sand of opportunity", derived from navigation projects and the construction of coastal facilities.

Several opportunistic nourishment projects in California have been associated with the construction of harbor facilities. Over 7 million cubic yards of sand, which became available during the construction of Newport Harbor, were placed on nearby beaches between 1919 and 1935 (Coastal Frontiers, 1999). Similarly, the ill-fated Navy Homeporting project planned to nourish San Diego County beaches with 7 million cubic yards of sand derived from channel deepening operations in San Diego Harbor (SANDAG, 2000). Construction activities in support of coastal facilities, such as the San Onofre Nuclear Power Plant, also have provided material for beach nourishment (Flick, 1993).

Project History

Prior to significant human intervention in the early 1900's, Santa Monica Bay (Figure 6.6) was bordered by naturally narrow beaches. These conditions can be attributed to the paucity of natural sediment entering the littoral cell, high rates of alongshore sediment transport, and the fact that most of the sand moving along the shoreline eventually was lost down the Redondo Submarine Canyon. The result was beach widths typically ranging from 50 to 150 feet, similar to conditions that persist today in the Malibu area, where artificial nourishment has been minimal or nonexistent.

Beach nourishment in Santa Monica Bay began in 1938. As indicated in Table 6.2 and graphically in Figure 6.7, over 31 million cubic yards of sand have been placed on the region's beaches. More than 90% of this material was "sand of opportunity".

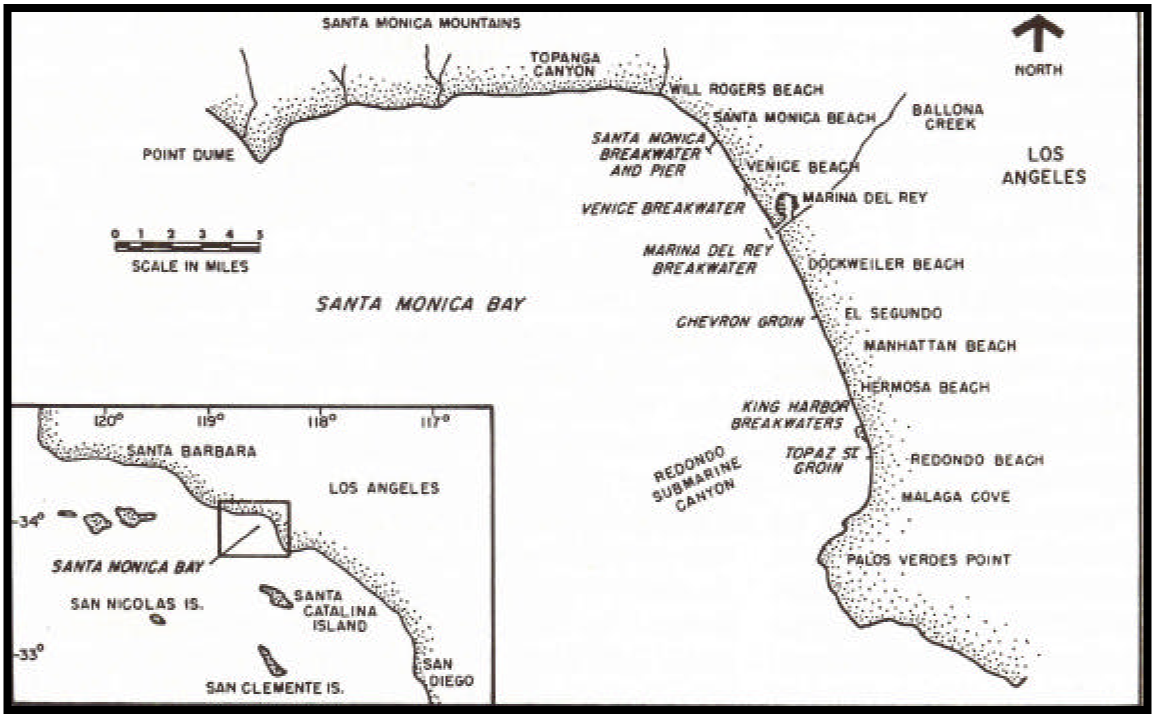


Figure 6.6 Santa Monica Bay location map

The Hyperion Sewage Treatment Facility site represents the single largest contributor of nourishment material to the Santa Monica Bay shoreline. Construction and subsequent expansion activities at the facility, located adjacent to Dockweiler Beach, supplied nearly 17 million cubic yards of dune sand for the beaches between Santa Monica and El Segundo from 1938 to 1989. The largest nourishment operation, conducted in 1947, provided 13.9 million cubic yards of sand to nourish 7 miles of shoreline at Dockweiler Beach.

The other principle source of opportunistic nourishment has been Marina del Rey. During construction of the harbor, between 1960 and 1963, over 10 million cubic yards of sediment were dredged from the small-craft basin and entrance channel and placed on Dockweiler Beach. This material contained a higher percentage of fine sediment than the relatively coarse material derived from the Hyperion project (Herron in USACE, 1986).

Coastal structures have been built along the Santa Monica Bay coastline since the late 1800's. By the 1960's, the large number of structures had effectively compartmentalized the shoreline between Topanga Canyon and Malaga Cove. This section of coast currently contains 5 shore-parallel breakwaters, 3 shore-perpendicular jetties, 19 groins, 5 revetments, and 6 open-pile piers (Coastal Frontiers, 1992). The major sediment-blocking structures are identified in Figure 6.6.

Table 6.2 Beach Nourishment in Santa Monica Bay

Date	Placement Site	Source	Classification	Quantity
1938	Dockweiler Beach	Hyperion	Opportunistic Nourishment	1,800,000 cy
1945	Venice Beach	Hyperion	Opportunistic Nourishment	150,000 cy
1947	Venice/Dockweiler	Hyperion	Opportunistic Nourishment	13,900,000 cy
1947	Redondo Beach	Onshore	Deterministic Nourishment	100,000 cy
1956	Dockweiler Beach	Scattergood	Opportunistic Nourishment	2,400,000 cy
1960-62	Dockweiler Beach	Marina del Rey	Opportunistic Nourishment	3,200,000 cy
1963	Dockweiler Beach	Marina del Rey	Opportunistic Nourishment	6,900,000 cy
1968-69	Redondo Beach	Offshore	Deterministic Nourishment	1,400,000 cy
1984	El Segundo	Offshore	Deterministic Nourishment	620,000 cy
1988	Dockweiler Beach	Hyperion	Opportunistic Nourishment	155,000 cy
1988-89	El Segundo	Hyperion	Opportunistic Nourishment	945,000 cy

Source: Coastal Frontiers, 1992

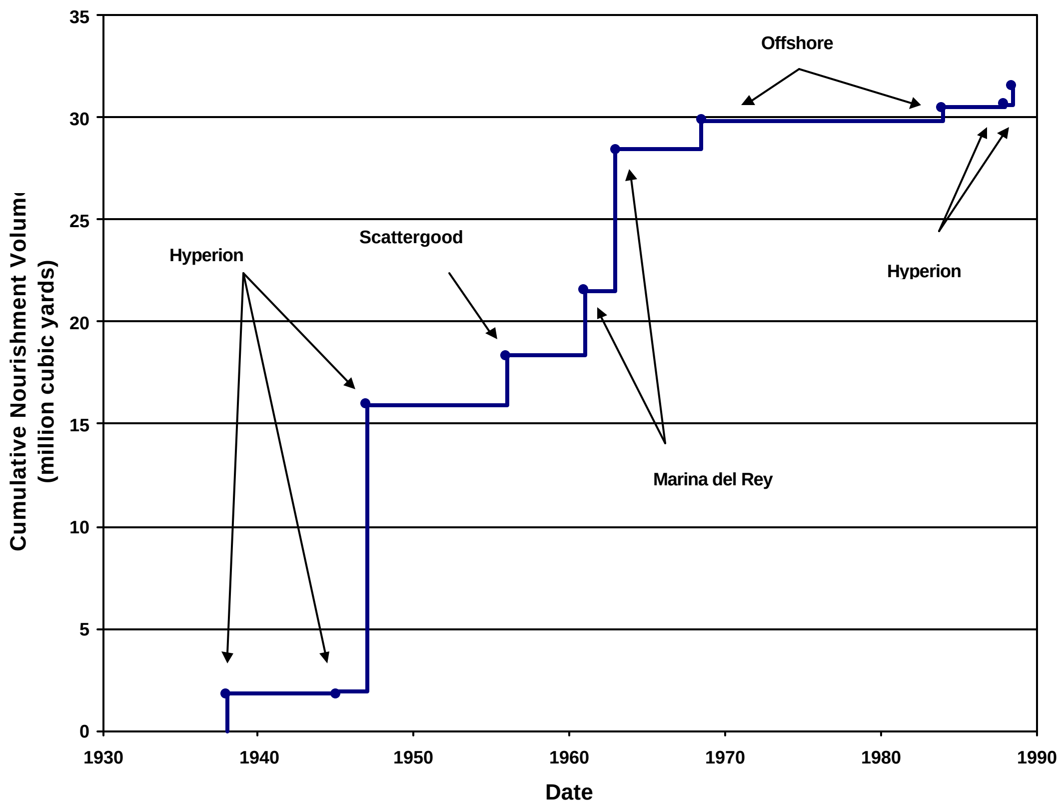


Figure 6.7 Cumulative nourishment for Santa Monica Bay beaches, 1938-1989

Project Performance

In contrast to the beach nourishment work performed in Orange County (Section 6.2.1), the projects discussed above were conducted in the absence of a regional shoreline plan. However, the cumulative effect of these independent projects was the creation of the wide, sandy beaches that draw over 50 million visitors per year to the Los Angeles County coast (Leidersdorf et al., 1993). In their natural condition, these beaches were incapable of supporting the recreational needs of the developing region, much less the demands of the present-day population.

The most substantial shoreline changes occurred in the southern and central portions of Santa Monica Bay, where beach nourishment was most prevalent. Santa Monica beaches are shown in Plate 6.8. A study commissioned by the Los Angeles County Department of Beaches and Harbors (Coastal Frontiers, 1992) found that the shoreline measured in 1990 was located well seaward of the 1935 position in all areas that received nourishment material. As shown in Table 6.3, the greatest shoreline advance relative to the 1935 baseline condition occurred at Dockweiler Beach, the beneficiary of the Hyperion and Marina del Rey opportunistic beach fills.

Plate 6.8 Wide, stable beaches at Santa Monica, 1993

Table 6.3 Average Beach Width Increases in Santa Monica Bay, 1935 - 1990

Location	Average Beach Width Increase
Santa Monica and Venice Beach	400 ft
Dockweiler Beach	500 ft
Manhattan and Hermosa Beach	250 ft
Redondo Beach	150 ft

Source: Leidersdorf et al., 1994

The magnitude of the shoreline changes is illustrated in Figure 6.8, which shows representative beach profiles in Venice Beach. The 55-year period of record encompasses all of the major beach nourishment operations conducted in Santa Monica Bay, accounting for nearly 31.6 million cubic yards of material. As a result of the 1947 Hyperion fill, the beach width and nearshore sediment volume increased dramatically by the time of the 1953 profile survey. Over the following 37-year period the beach remained remarkably stable, retaining most of the sand from the prior nourishment.

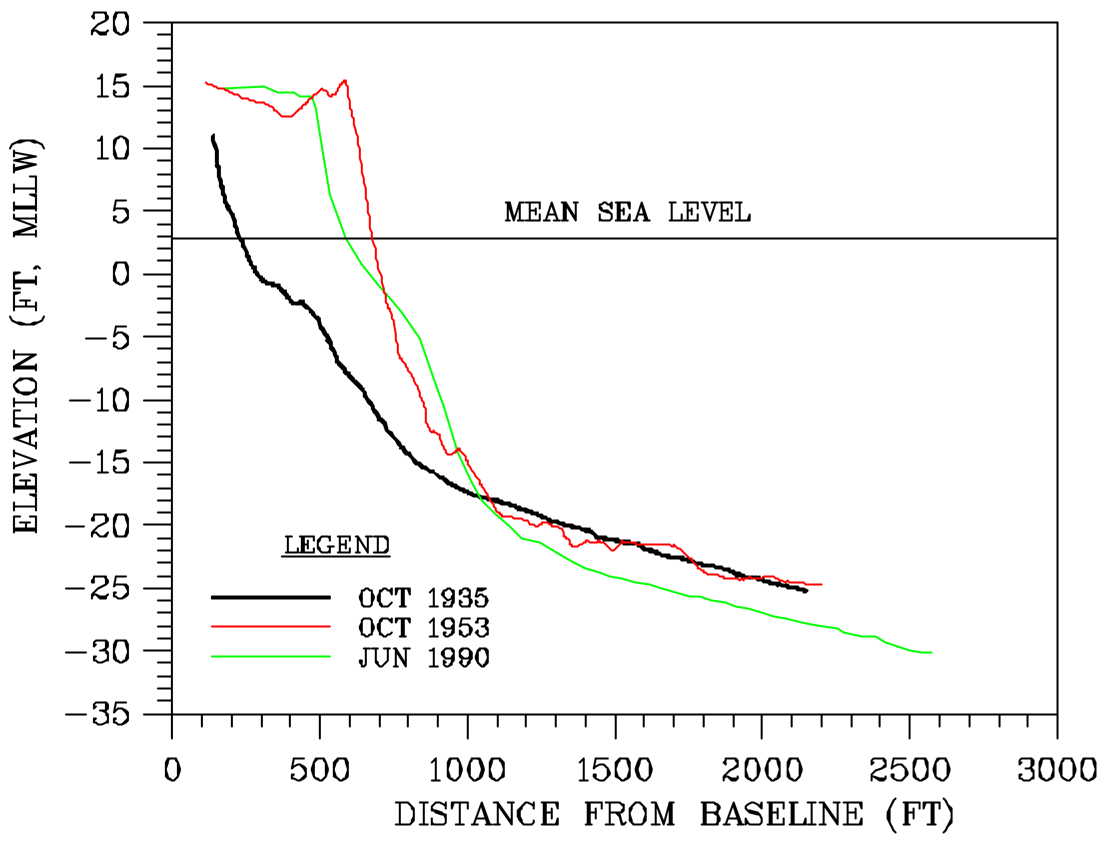


Figure 6.8 Representative beach profiles in Venice Beach

The stability of the beaches in Santa Monica Bay, and hence the longevity of the beach nourishment material, can be attributed partially to the structural compartmentalization of the shoreline. The numerous breakwaters, jetties and groins in the reach are extremely effective in limiting alongshore transport and retaining sand (Flick, 1993). In the absence of these structures, waves and currents would continue to move large quantities of sand downcoast and into the Redondo Submarine Canyon. Combined with the lack of natural sediment supply to the system, the extremely wide beaches in Santa Monica Bay would probably not be realized today without these artificial features.

6.3.2 West Newport Beach Nearshore Nourishment Project

In 1992, nearly 1.3 million cubic yards of beach quality sediment were placed in a nearshore sand bar off the coast of Newport Beach. All of the material was "sand of opportunity", derived from a flood control project in the nearby Santa Ana River.

The nearshore nourishment project at Newport Beach is representative of similar projects that have been conducted or are currently under consideration at other California locations. Material from maintenance dredging at San Diego Harbor has been used for nearshore nourishment off the coast of Imperial Beach (SANDAG, 2000). In Santa Barbara and Ventura Counties, nearshore sand placement is a major component of BEACON's proposed regional shoreline plan (BEACON, 2000).

Project History

The Lower Santa Ana River Flood Control Channel Expansion Project plan required the dredging and disposal of accumulated material in the river bed between the San Diego Freeway and the ocean outlet. A nourishment project was devised to reduce disposal costs and to take advantage of the large quantities of beach-grade sand. Operations were conducted between January and November 1992.

Nearly 1.3 million cubic yards of dredged material were deposited offshore of Newport Beach in water depths of 15 to 30 feet. The nourishment site (Figure 6.9), located southeast of the Santa Ana River mouth, was selected in hopes that the material would be contained between the Santa Ana River jetties and the West Newport groin field (Mesa, 1996).

Unlike traditional nourishment techniques, an immediate increase in beach width is not achieved with nearshore placement. To be effective, the material must be placed within the active portion of the littoral system. Beach widths increase gradually as the sand moves onshore under the influence of waves and currents.

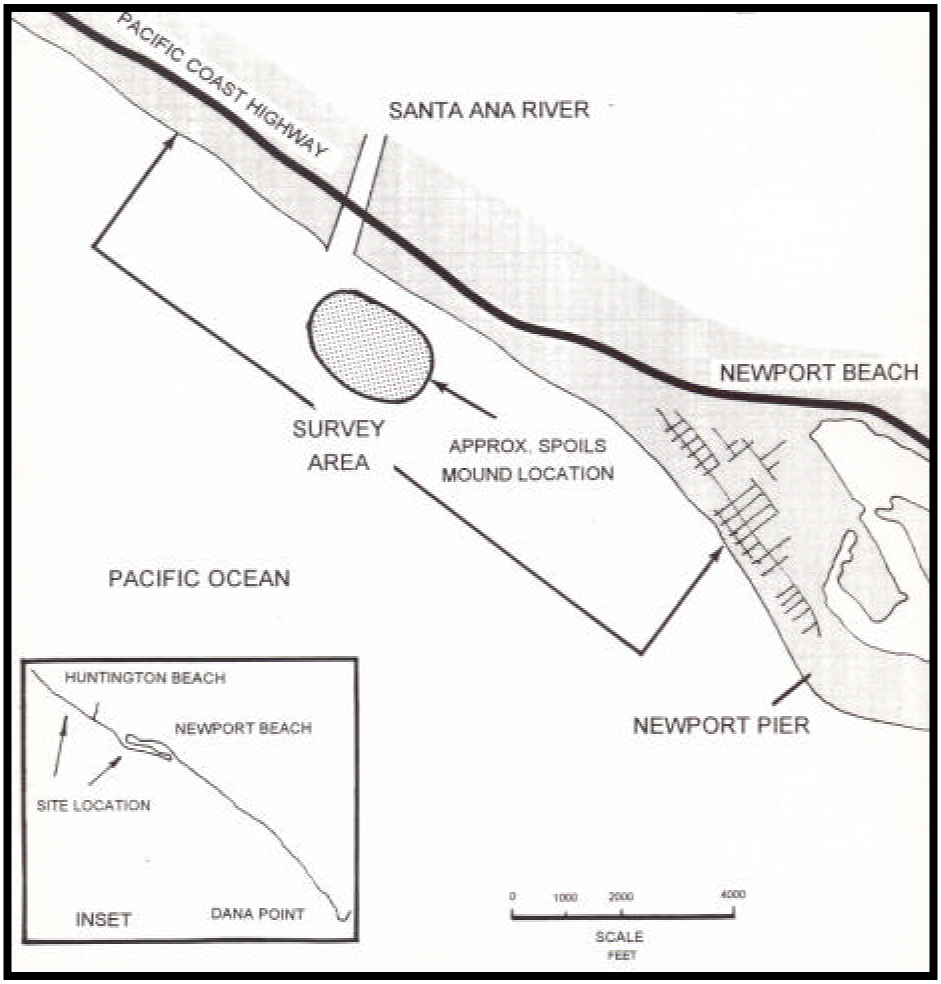


Figure 6.9 West Newport Beach Nearshore Nourishment Project location map

Project Performance

The nearshore nourishment sand bar progressively eroded and dispersed following placement. Survey results from the post-construction monitoring program, shown in Figure 6.10, indicate that material from the crest of the bar migrated landward in response to waves and currents. There was no definitive evidence to support offshore or alongshore migration of the mound (Mesa, 1996).

Beach widths measured in the vicinity of the project are shown in Figure 6.11. A pronounced trend of shoreline advance is evident during the five-year period (1992-1997) following project implementation. The shoreline changes reflect the onshore migration of sediment, as well as the wave sheltering effects of the sand bar. Similar increases at downcoast beaches were less evident.

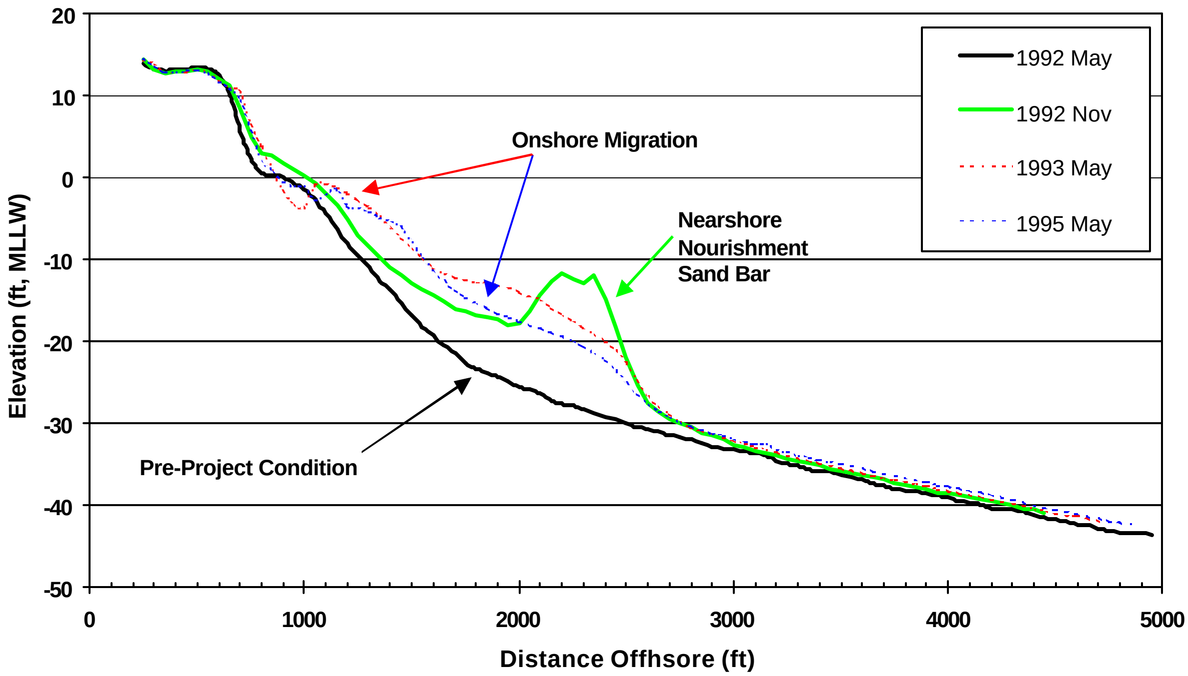


Figure 6.10 Beach profiles through West Newport nearshore mound

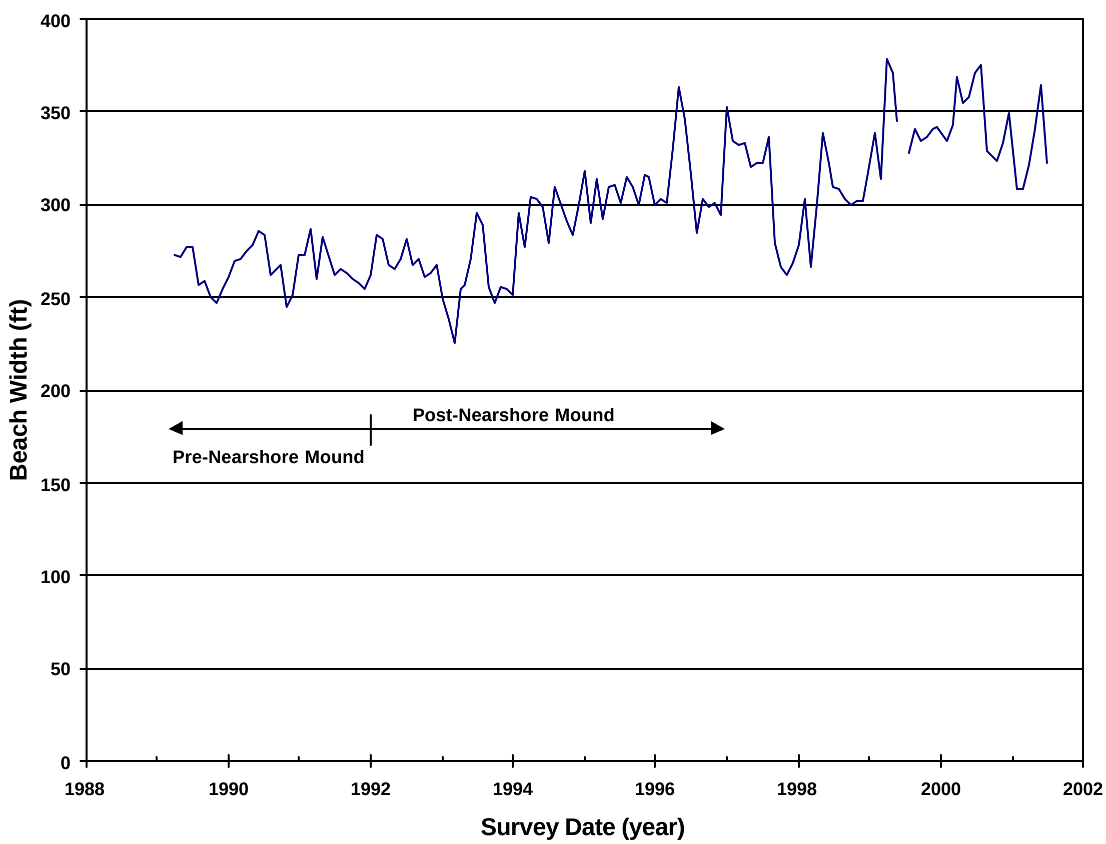


Figure 6.11 Beach width in vicinity of West Newport nearshore mound, 1989-2001

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Part 3

7. IMPEDIMENTS TO FLUVIAL DELIVERY OF SEDIMENT TO THE SHORELINE

7.1 Introduction

Sediment budget studies have estimated that coastal rivers and streams supply, on average, 70 to 90% of beach sand in California (Bowen and Inman, 1966; Best and Griggs, 1991). Accompanying the explosive growth and land use change in California's coastal watersheds over the twentieth century, 480 major dams and reservoirs, nearly 200 debris basins, hundreds of in-stream sand and gravel extraction operations (Kaufman and Pilkey, 1979; Brownlie and Taylor, 1981), and hundreds of miles of stream bank and bed channelization have reduced fluvial sediment transport to a fraction of natural rates. Rates and magnitudes of fluvial sediment delivery have been altered significantly from long-term natural rates by the construction of barriers to sediment transport and land use changes that have modified watershed erosion rates (i.e. sediment production). This report makes a substantive effort to quantify the reduction in sediment supplied to the coast due to the impacts of major dams, debris basins, and channelized streams. Alterations in watershed sediment yield due to land-use changes and the effects of in-stream sediment mining are not addressed in this report but are important topics for future research.

7.1.1 Overview

Sediment is delivered to the river and stream channel by basin erosion processes including hill slope creep, overland flow, landslides, and debris flows. Once delivered to the channel, sediment is transported down the channel network as dissolved or solid load. Solid load, the dominant mode of fluvial transport in California, includes both suspended sediment—sediment that it is fully entrained in the moving water column—and bedload—coarser material that rolls or bounces along the stream bed. About 85 to 95% of all sediment is carried as suspended load; however, only 10 to 38% of this sediment is sand-size material (grain diameter between 0.062 and 2.00 mm) that could contribute to beach supplies. Bedload, which typically ranges from 5 to 15% of the total sediment load (Collins and Dunne, 1990; Inman and Jenkins, 1999), is comprised almost entirely of sand- or larger-size sediment. The amount of sediment in transport at any given time depends on both the magnitude of stream flow and grain size of sediment present on the streambed. Basin relief, the magnitude and intensity of precipitation events, antecedent rainfall conditions, soil and underlying bedrock types, density of vegetation, and land-use are among the important climatic and geologic variables that determine the magnitude of stream flows and the types of sediment present on the stream bed. Sediment in transport in coastal fluvial systems ultimately will be stored within the basin—either in the stream channel, in the flood plain adjacent to the stream, or in an estuary at the stream mouth—or it will be delivered directly to the ocean. When sediment is delivered to the coast, the fine silts and clays are quickly moved offshore by wind- and wave-generated currents, while the sands and gravels are deposited near the river mouth as beach or delta deposits, which are available for transport along the coast by longshore currents.

California's coastal watersheds are of two general types: (1) the steep, erodible, conifer-forested Coast Range basins north of Monterey Bay, which are characterized by high seasonal rainfall and perennial streams, and (2) the more arid basins of Central and Southern California, which often drain chaparral- or grassland-covered headwaters, but may cross broad alluvial valleys in the their lower reaches. On average, the state's coastal watersheds receive 82% of the annual precipitation between November and March (National Climate Data Center, 2001). As a result, almost all sediment is brought to the coast during storms over these winter months. Northern California, depicted in Figure 7.1 as Division 1, receives an average of 42 inches of rain annually, while Central and Southern California (Divisions 4 and 6) receive annual averages of 21 and 17 inches, respectively (National Climate Data Center, 2001).

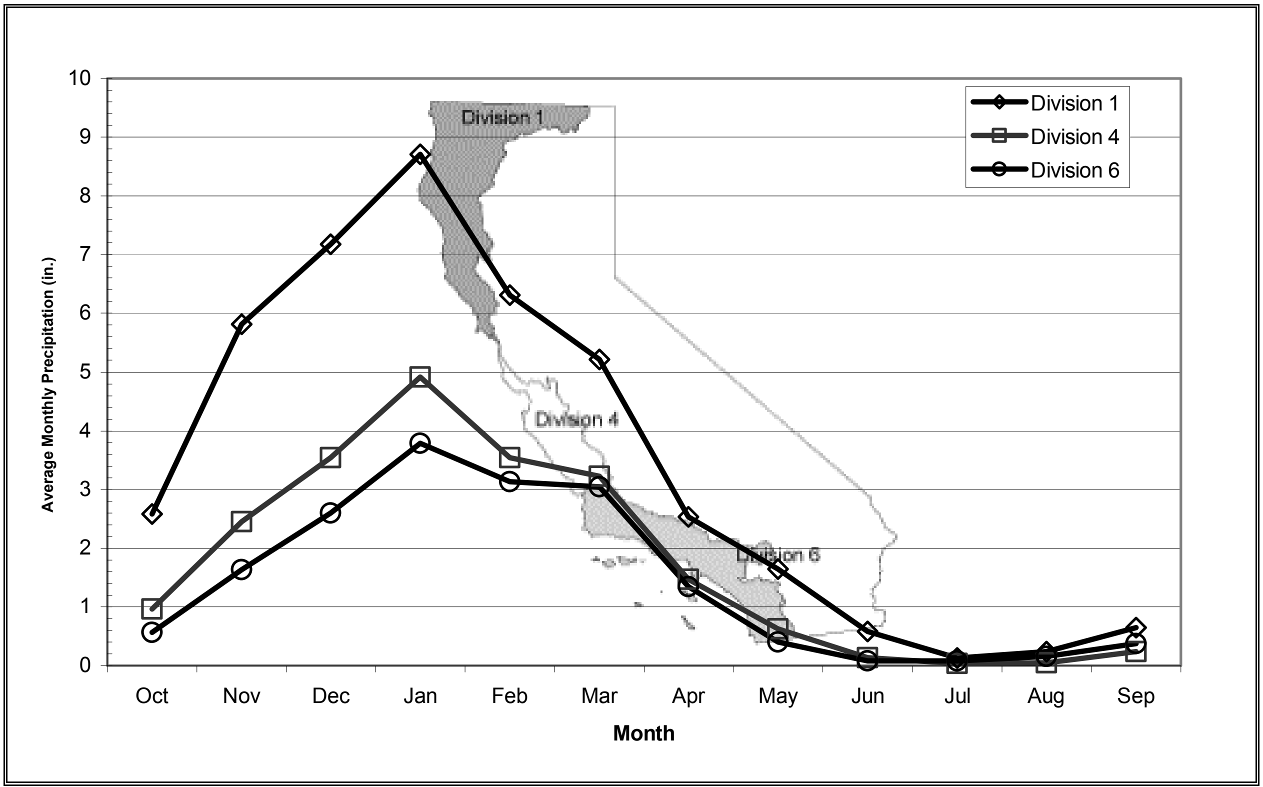


Figure 7.1 Regional comparison of average monthly precipitation, water years 1886 to 2000

(Data Source: National Climate Data Center, 2001)

This regional imbalance in precipitation results in a regional gradient in average daily water discharge. Figure 7.2 shows the average monthly discharge for three minimally-impeded rivers draining similar size basins (100 to 150 square miles), for which less than 5% of the basin areas are controlled by dams. Peak discharges tend to occur in all three regions during January, February, and March when soils have reached saturation and additional rainfall is translated directly into run-off. This seasonal pattern of rainfall and streamflow depicted in Figures 7.1 and 7.2 is heightened by infrequent, exceptionally wet years when large floods flush enormous quantities of sediment out of coastal watersheds. A study of major rivers in Central and Southern California has shown that sediment discharge during flood years like 1969, 1983, or 1998 averages 27 times greater than during drier years (Inman and Jenkins, 1999). For example, in 1969 over 100 million tons of sediment were flushed out of the Santa Ynez mountains, more than the previous 25 years combined (Inman and Jenkins, 1999). Similarly, on the San Lorenzo River near Santa Cruz, CA, 63% of all the suspended sediment transported between 1936 and 1998 occurred over just 62 days (or less than 0.3% of the time over the 52 year period). These infrequent, severe floods occurring every 10 to 20 years are responsible for delivering the majority of beach material to the coast.

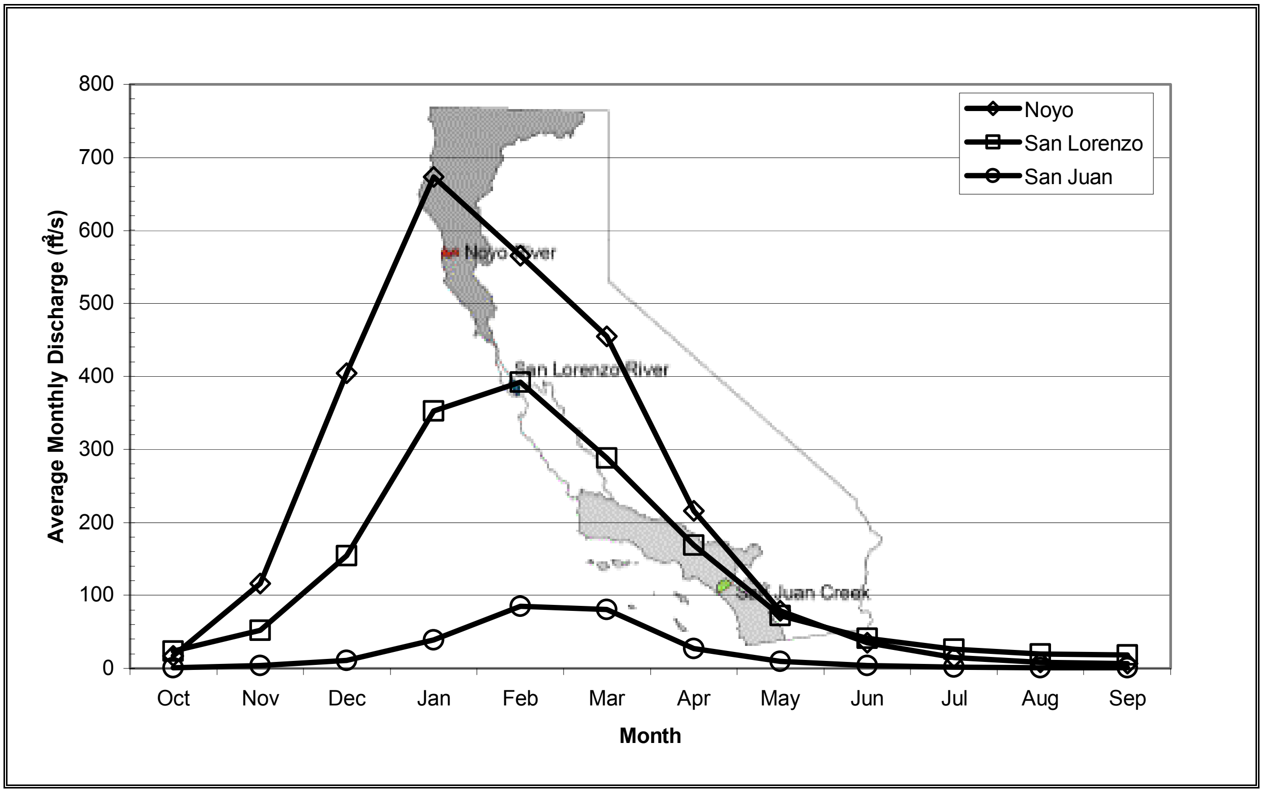


Figure 7.2 Regional comparison of average monthly water discharge, water years 1952 to 1999
*(*Data Source: USGS Water Resources Data, 1952-1999*)*

California's coastal rivers have exceptionally high sediment loads due to the steep topography, the geologically young and tectonically active terrain, and, in Central and Southern California, the relatively sparse vegetative cover. Sediment yield, the volume of sediment delivered per square mile of watershed, is typically very high in California relative to other major hydrographic regions of the United States. In fact, the Eel River in Northern California has the highest sediment yield of any river its size in the U.S. (Brown and Ritter, 1971) and discharges, on average, more sediment per year than any other river in the lower 48 states other than the Mississippi River (Meade and Parker, 1984).

7.1.2 Fluvial Sediment Input, by Watershed/Littoral Cell, from Major Waterways

In this study, all water discharge and sediment data published by the USGS through the 1999 water year (USGS Water Resources Data for California, 1999) has been compiled for the most seaward gaging stations for California's 34 gaged coastal streams to characterize the long-term fluvial delivery of beach material to the coast. Suspended sediment transport was estimated using a standard rating curve technique, where suspended sediment measurements are correlated with water discharge by a power function of the form $Q_s = a \cdot [Q_w]^b$, where Q_s is the daily suspended sediment flux (tons/day), Q_w is mean daily water discharge in ft^3/s, and a and b are constants. The daily estimated and measured suspended sediment fluxes were summed by water year. Suspended sediment grain size was found to have a very poor correlation with water discharge, presumably due to the variable supply of sediment on the bed through time. Therefore, the average value of the percent of sand in suspension was used to reduce annual suspended sediment delivery to just the volume of sand delivered in that year. Bedload rating curves were developed when data were available and grain size information from the bed surface was used to assess the sand and gravel fraction of the bedload. The annual suspended sand and bed sand and gravel fluxes were summed together to determine the total annual flux of beach material (Q_L). The average annual sand and gravel discharge (Q_L) was calculated over the period of record to reflect the long-term average sand and gravel discharge for each river. When bedload information was not available, bedload was assumed to be 10% of the annual suspended sediment flux and 100% sand or coarser, an estimate often used by researchers in lieu of direct measurements (Brownlie and Taylor, 1981; Hadley et al., 1985; Inman and Jenkins, 1999). Errors in estimating suspended sediment flux arise from measurement errors of suspended sediment in the field and statistical errors in rating curve calculations. Overall uncertainty for suspended sediment discharge estimates has been estimated at a maximum of ±35% (Inman and Jenkins, 1999). In a few cases, no suspended sediment data were available, so long-term sediment flux was based on reservoir sediment accumulation rates within the basin or sediment yields of adjacent watersheds. For example, accumulation rates in three reservoirs in the Santa Ynez basin indicate an average sand and gravel yield of 440 yd^3/mi^2-yr; this average yield was applied to the Santa Ynez watershed area not affected by dams to estimate the long-term average annual sand and gravel yield. For 5 rivers that had neither suspended sediment nor sediment accumulation data, Q_L was estimated by applying the average annual sand and gravel yield of adjacent watersheds with sediment data to the basin area not affected by dams. Previously-published estimates of sand and gravel discharge were used for 5 Southern California rivers.

Table 7.1 summarizes the long-term average annual sand and gravel discharge (Q_L) from all major gaged streams in California. The sand discharge includes all sand-sized material (0.062

to 2.0 mm), but sediment budget studies along the California coast have found that much of the fine sand (between 0.062 and 0.125 mm) is too small to remain on the beach (Ritter, 1972; Best and Griggs, 1991). Therefore, the sand flux estimates provided in Table 7.1 should be considered maximum estimates of beach quality material supplied from coastal streams. It is worthwhile to note that the sand flux in any given year does not necessarily reflect the average annual sand flux reported in Table 7.1. Sediment delivery is a highly episodic process in which extremely wet years deliver most of the sediment to the coast as discussed in the previous section. Thus, the average annual flux includes both the occasional high discharge years and the more frequent moderate and low flow years. This concept is illustrated for two rivers with similar basin sizes and less than 5% of their drainage areas impacted by dams, the San Lorenzo River and San Juan Creek (Figure 7.3). Southern California rivers, like San Juan Creek, appear to experience more extreme episodicity in sediment delivery than rivers in Central and Northern California.

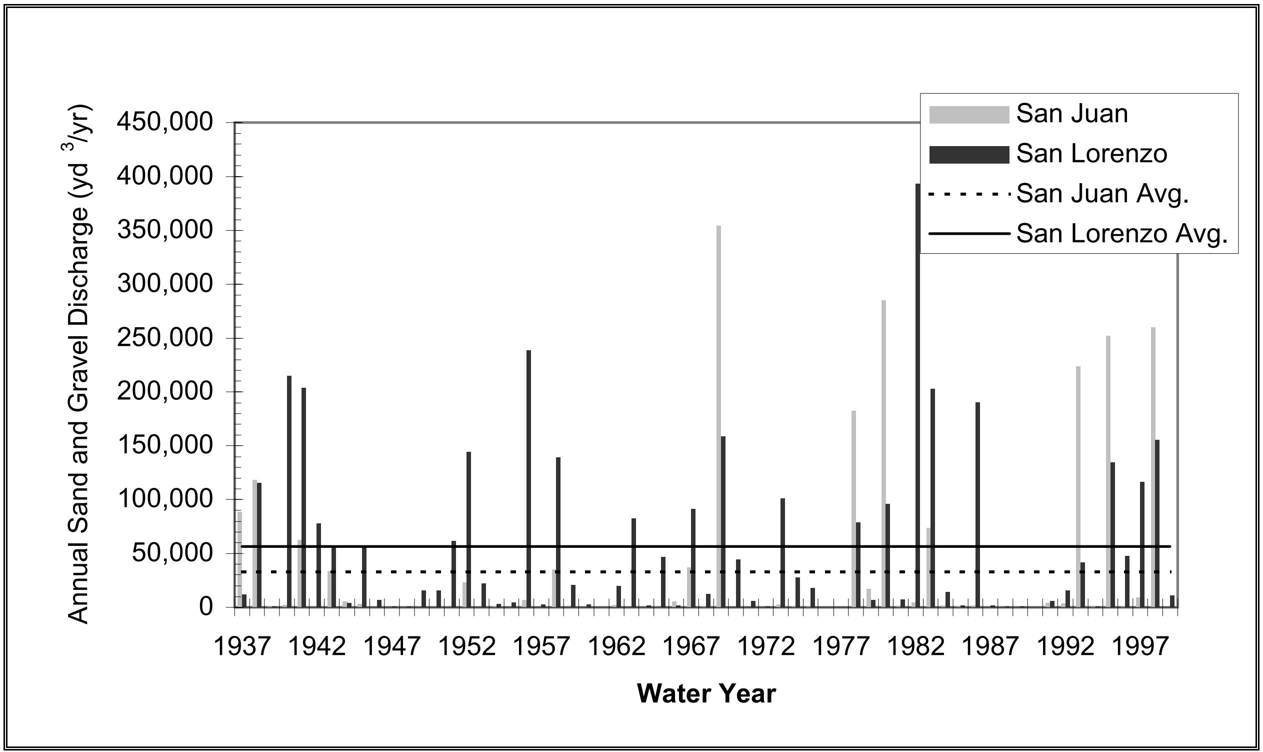


Figure 7.3 Comparison of San Lorenzo River and San Juan Creek annual sediment delivery, water years 1937 to 1999

Table 7.1 Summary of Average Annual Sediment Discharge for Major California Rivers

(Source: Data developed in this study unless noted otherwise)

Major Rivers	Average Annual Flux Q_L (yd^3/yr)	Period (Water Yr)	Area above gage (mi^2)	Sand and Gravel Yield (yd^3/mi^2-yr)
Smith River [a]	178,503	1932 - 1999	614	291
Klamath River [a]	1,668,122	11-26, 55-96, 98-99	12,100	138
Redwood Creek [a]	335,205	1954 - 1999	277	1,210
Little River [b]	53,208	NA	41	1,314
Mad River [a]	687,340	1951 - 1999	485	1,417
Eel River [a]	3,753,107	1917 - 1999	3,113	1,206
Mattole River [b]	232,295	NA	245	947
Noyo River [b]	100,417	NA	106	947
Navarro River [a]	208,868	1951 - 1999	303	689
Russian River [a]	183,106	1940 - 1999	1,338	137
Pescadero Creek [a]	9,294	1952 - 99	46	202
San Lorenzo River [a]	56,359	1937 - 99	106	532
Pajaro River [a]	60,475	1940 - 99	1,186	51
Salinas River [a]	488,734	1930 - 99	4,156	118
Carmel River [a]	32,265	1963 - 99	246	131
Arroyo Grande	37,325	1940 - 86	102	366
Santa Maria River [a]	260,764	1941 - 87	1,741	150
San Antonio Creek [b]	60,290	NA	135	447
Santa Ynez River [c]	347,078	1920-99	789	440
Ventura River [a]	102,252	1930 - 99	188	544
Santa Clara River [a]	1,193,102	1928 - 32, 1950 - 99	1,594	748
Calleguas Creek [a]	64,932	1969 - 99	243	267
Malibu Creek [1]	34,007	1960 - 99	100	238
Ballona Creek [2]	2,890	1944 - 95	130	22
Los Angeles River [a]	77,187	1930 - 83, 1989 - 92	827	93
San Gabriel River [b]	59,246	NA	709	84
Santa Ana River [a]	125,316	1924 - 99	1,700	74
San Diego Creek [a]	16,208	1950 - 85	42	388
San Juan Creek [a]	29,874	1929 - 99	109	274
Santa Margarita River [a]	39,877	1931 - 98	723	55
San Luis Rey River [a]	39,907	1947 - 97	557	72
San Dieguito River [3]	12,507	1919 - 78	338	37
San Diego River [3]	6,581	1913 - 75	377	17
Tijuana River [3]	42,100	1937 - 75	1,695	25

[a] Q_L derived from measured suspended sediment data, bedload data, and rating curves

[b] Q_L based on watershed area and sediment yield of adjacent basins

[c] Q_L based on watershed area and sediment accumulation data

[1] Knur, 2001

[2] Inman & Jenkins, 1999

[3] Brownlie and Taylor, 1981

7.2 Dams

Central and Southern California are the sites of the state's main urban centers: the San Francisco Bay area, Los Angeles, and San Diego. Major agricultural regions—San Joaquin Valley, Salinas Valley, and Imperial Valley—also are located in this region. Today, 56% of California's 34.3 million residents live in the coastal counties from San Francisco to San Diego (California Department of Finance, 2000), but the majority of the state's precipitation—75%— falls north of San Francisco (California Rivers Assessment, 1992). To meet the urban and agricultural water demands, California has developed a complex network of dams, reservoirs, and aqueducts capable of storing 60% of the state's annual runoff and transporting it from water-rich Northern California to water-poor Central and Southern California (California Rivers Assessment, 1992).

To support California's exponential population growth over the twentieth century, over 1,400 large dams have been constructed across the state for a number of purposes, including water storage, irrigation, flood control, recreation, and hydroelectric power (see Figure 7.4). There are undoubtedly a much larger number of small dams and obstructions that inhibit sediment transport in California streams; however, this study only addresses dams that fall under the jurisdiction of the California Department of Water Resources Division of Safety of Dams (Division of Safety of Dams, 1998), which include dams that are either at least 25 feet high or impound 50 or more acre-feet of water.

7.2.1 Inventory of jurisdictional dams and reservoirs

Since the construction of the first major dam in California in 1866, an average of 3.5 dams per year have been built, for a total of 480 dams in the study area. An additional 60 dams in Oregon and Mexico affect flows in California's coastal watersheds. The study area includes all watershed area that drains directly to the Pacific Ocean (Figure 7.4), excluding areas draining to the San Francisco Bay. The primary purposes of dams in this area are water supply (33%), irrigation (21%), flood control (19%), and recreation (11%) (EPA, 1998). The majority of coastal dams are owned and operated by local governments and water districts (52%), followed by private companies or individuals (31%), and federal (13%) and state agencies (4%) (Division of Safety of Dams, 1998).

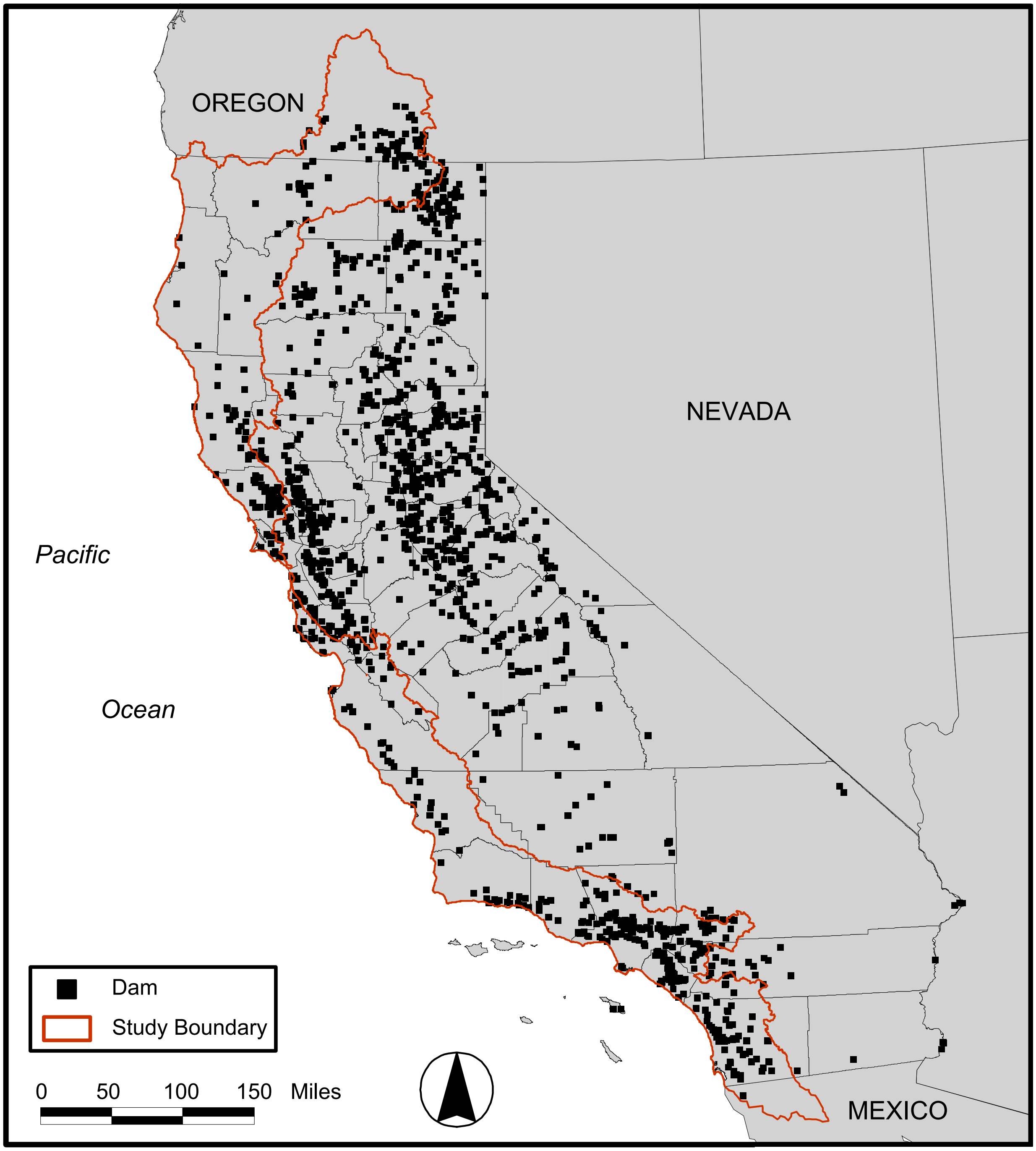


Figure 7.4 Distribution of Large Dams in California

(Data Source: Division of Safety of Dams, 1998)

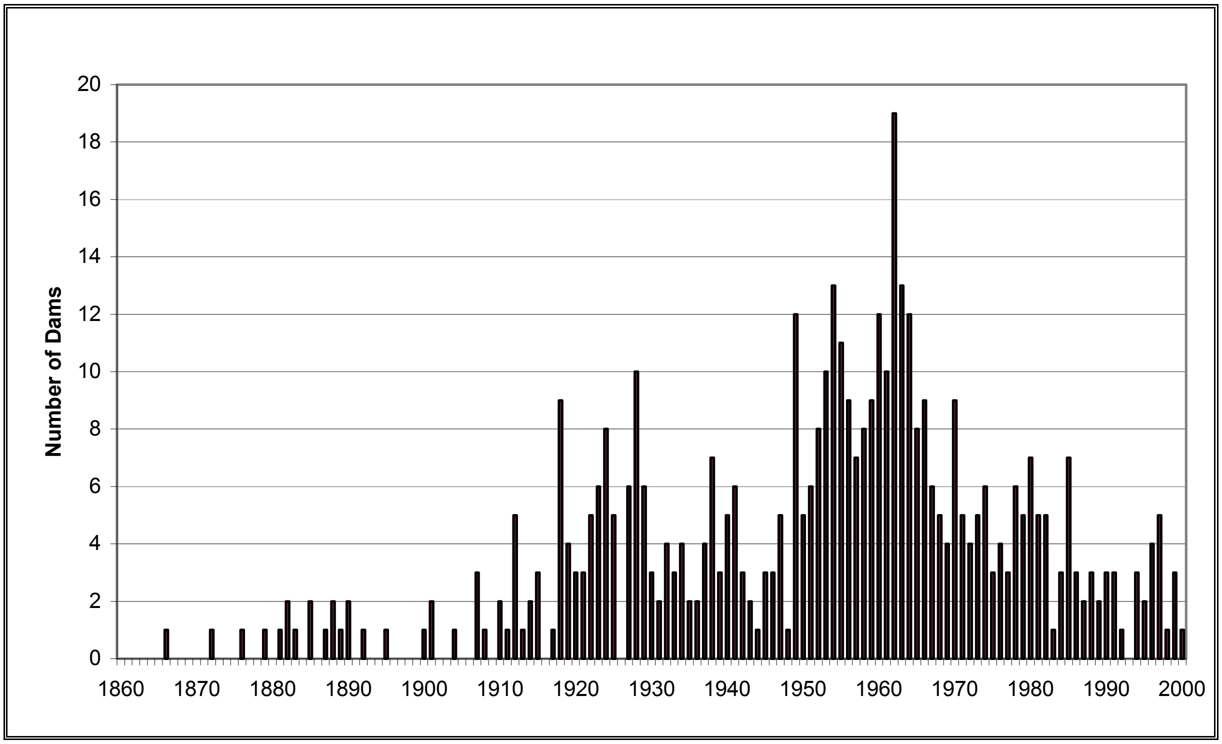


Figure 7.5 Number of dams built each year in California coastal watersheds, 1860 to 2000
(Data Source: Division of Safety of Dams, 1998)

Dam construction trends can be assessed by either the number of individual dams built in a year or by the cumulative water storage or flood control capacity. By both accounts, maximum activity occurred between 1945 and 1977, when 61% of the water storage capacity and 50% of the total number of dams in the study area were built (Figures 7.5 and 7.6). This time period coincides with a prolonged period of below-average rainfall in Southern California (where 58% of the dams in the study area reside): below-average precipitation fell in 27 of the 33 years (82%; National Climate Data Center, 2001). In addition, this time period is marked by two decades of exceptionally high rates of population growth for the 20th century (California Department of Finance, 2000). Since 1978, California has experienced 3 strong El Niño events and 14 of 22 years (65%; National Climate Data Center, 2001) with above-average precipitation. Despite the relatively wet climatic conditions dominant since 1978, 20% of the coastal water storage capacity has been built since 1990, including the largest dam in the study area, the Diamond Valley Lake (formerly called Eastside Reservoir), designed to store 800,000 acre-ft of water (Division of Safety of Dams, 1998). The total water storage capacity of the coastal dams represents only 12% of the total statewide water storage capacity (42.6 million acre-ft; California Rivers Assessment, 1992).

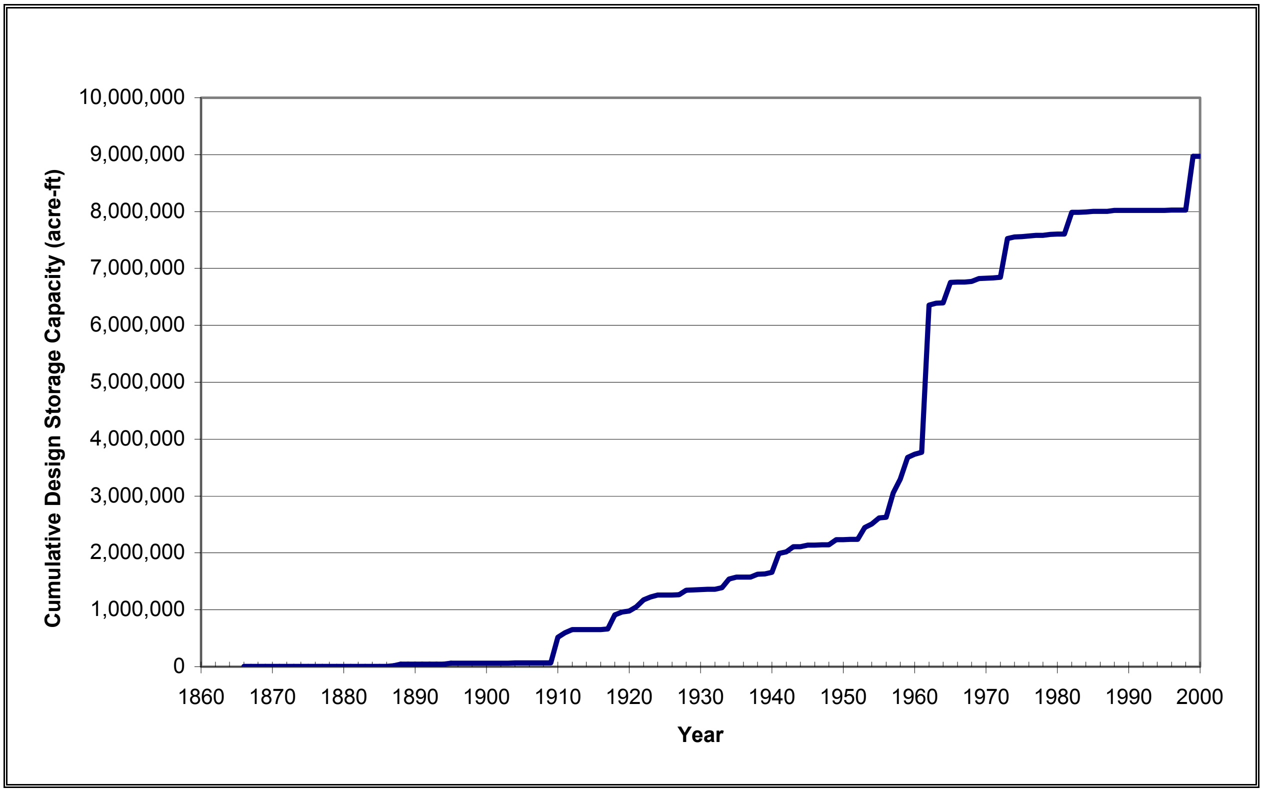


Figure 7.6 California coastal dam capacity through time, 1860 to 2000
(Data Source: Division of Safety of Dams, 1998)

California's water engineering system has drastically altered the natural behavior of most of the state's major rivers and streams. Dams change the magnitude and timing of river flows, trap sediment, alter river temperatures, and impede or completely obstruct the movement of fish upstream of the dam, contributing to the decline of Pacific salmon and steelhead trout populations in California. By trapping sediment and altering the hydrology of streams, dams can alter water discharges, sediment load, channel incision rates, and channel morphology below the dam (Williams and Wolman, 1984).

7.2.2 Impact of Dams on Sediment Discharge

Dams can reduce sediment supply to beaches in two ways: (1) by trapping sediment behind the dams and (2) by reducing peak river flows that transport sand below the dam. Upstream, dams create a reservoir of still water in which all bedload is trapped and all but the finest suspended sediment settles to the reservoir bottom. Brune (1953) demonstrated that the amount of suspended sediment impounded, or the trapping efficiency of dams, depends on the ratio of water inflow to reservoir capacity. For California's large reservoirs, the trapping efficiency is nearly 100% (Kondolf and Matthews, 1991). Channel degradation, bank erosion, and bed-coarsening have been documented immediately downstream of dams and have been attributed to the "hungry waters" effect—an increase in stream power resulting from reduced sediment loads

(Williams and Wolman, 1984; Kondolf and Matthews, 1991). More importantly for coastal sediment delivery, however, dams restrict the volume and speed of the water traveling in the river channel, diminishing the competence and capacity of the river to carry sediment. Researchers have also shown that dams on the main stems of rivers may disrupt the synchronous high flows on the main stem and tributaries with important implications for sediment transport (Topping et al., 2000).

As early as 1938, coastal researchers recognized the implications of the proliferation of dams in California's coastal watersheds on beach sand supply (Grant, 1938). Not until the latter half of the century, however, did researchers attempt to quantify the volume of sediment impounded by dams (Norris, 1963; DNOD, 1977; Brownlie and Taylor, 1981; Griggs 1987; Flick 1993). Brownlie and Taylor (1981) completed the most rigorous of these studies, estimating average annual sand reductions for watersheds in Southern California through the 1978 water year. Now, there are 21 additional years of discharge and sediment data with which to better characterize the degree to which dams have reduced sand supply to the coast.

In contrast to studies on other major rivers like the Colorado (Topping et al., 2000), the Missouri (Williams and Wolman, 1984), and the Green (Andrews, 1986), there are no published pre-dam sediment data for USGS gaging stations on regulated coastal streams in California to directly compare to post-dam sediment loads. When pre- and post-dam sediment transport data are available for a river, the reduction in sediment transported is evident (Figure 7.7).

For many streams in California, pre- and post-dam streamflow data are available, but because of the high degree of annual variability in streamflow it is difficult to distinguish between natural climate variability and the effects of dams in a statistically rigorous manner. Therefore, to quantify the role of dams in reducing sediment supply to the coast, we used two approaches in conducting this study: (1) the difference between daily water inflow and release rates to estimate natural flows and sediment transport at coastal gaging stations, using the methodology of Brownlie and Taylor (1981); or (2) using reservoir sediment accumulation data to assess the sediment yield of impounded watershed areas and the resulting reduction in sediment yield for the entire basin. For several streams in Southern California, estimates of sediment reduction by previous researchers were used, due either to a lack of new data (Santa Margarita, San Dieguito, San Diego, and Tijuana rivers) or to the complexity of the watersheds (Los Angeles, San Gabriel, and Santa Ana rivers). In addition to the sediment transport investigation, all major dams, streams, topography, and watersheds were entered in a geographic information system (GIS) to generate accurate maps and to permit spatial analysis. Watershed areas controlled by dams were delineated using 100-meter digital elevation models (DEMs) to illustrate the broad geographic influence of coastal dams.

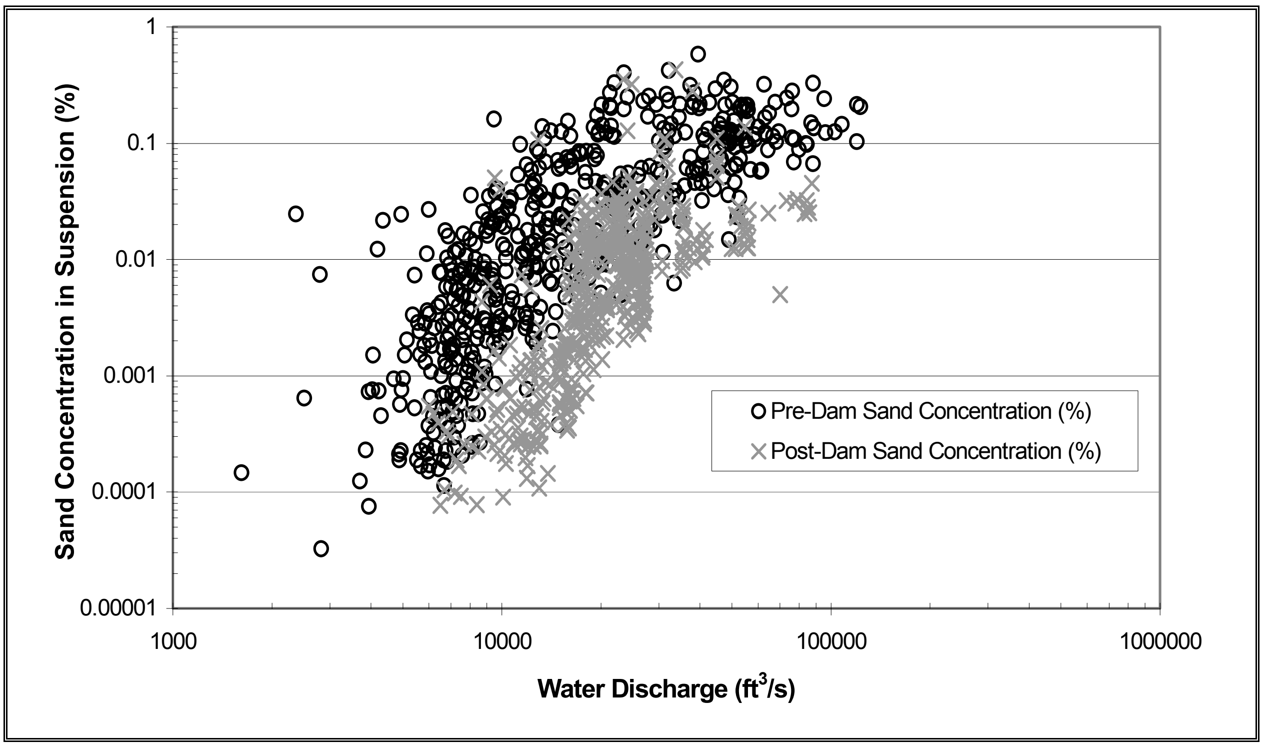


Figure 7.7 Comparison of measured sediment loads on the Colorado River before and after construction of Glen Canyon Dam

(Data provided by D. Rubin, USGS; measurements were made 90 miles downstream of the dam)

Dams affect more than 38% of California's coastal watershed area (Figure 7.8), impacting important habitat and sand contributions from over 16,000 mi^2 (an area roughly equivalent to the combined area of Massachusetts and New Hampshire).

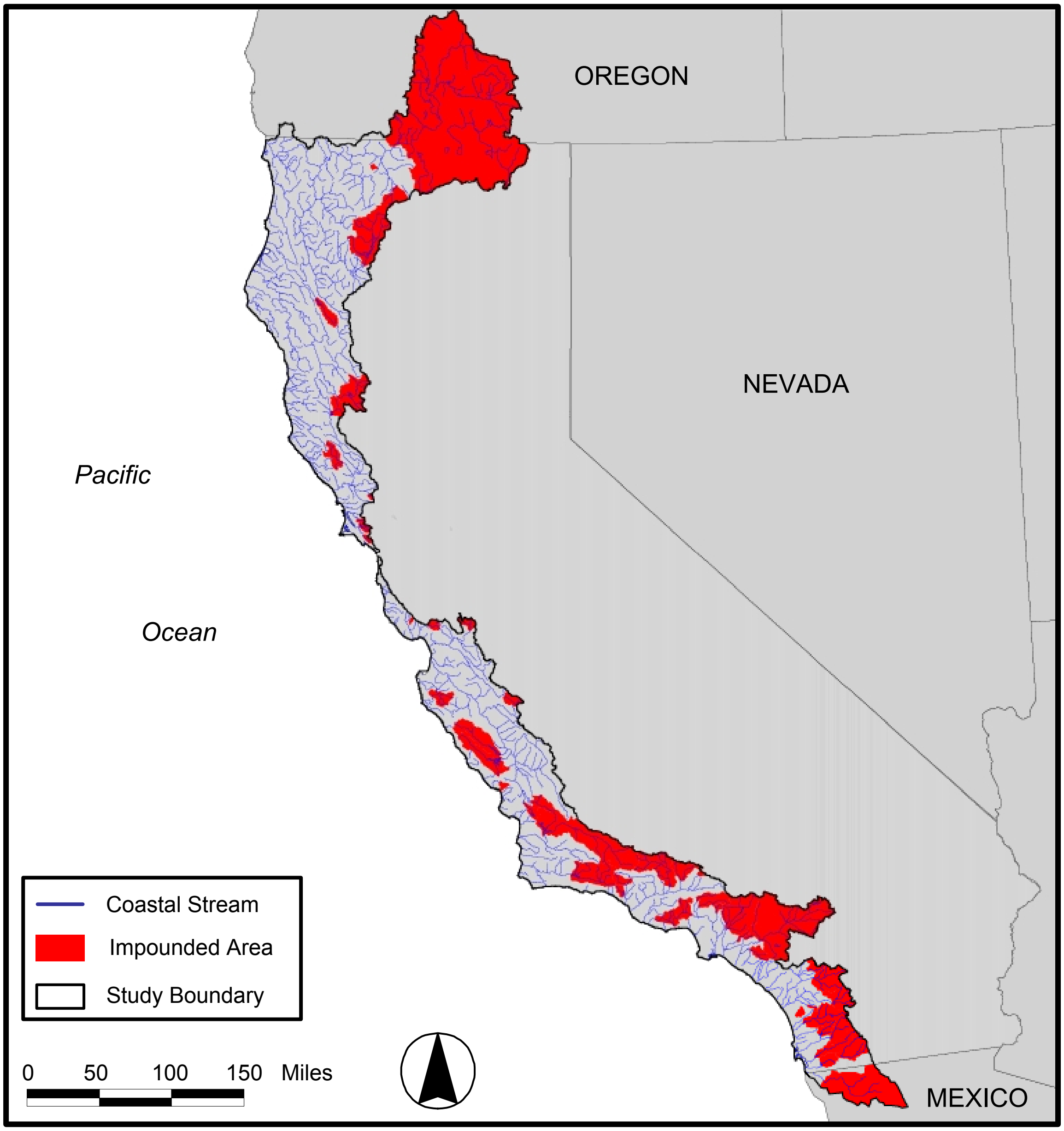


Figure 7.8 Major coastal watershed areas affected by dams

Table 7.2 summarizes the watershed areas controlled by dams, present average annual sediment yield for major coastal rivers, and the current level of reduction in sand and gravel supply due to dams.

Table 7.2 Summary of Sediment Reduction due to Dams by Littoral Cell

(Source: Data developed in this study unless noted otherwise)

Littoral Cell Name	Major Rivers	Percent Controlled	Present Avg. Annual Q_L Flux (yd^3/yr)	Present % Q_L Reduction
Smith River	Smith River	0	178,503	**0**
Klamath River	Klamath River	46	1,668,122	37
	Redwood Creek	0	335,205	0
	Total	45	2,003,327	**33**
Eel River	Little River	0	53,208	0
	Mad River	24	687,340	9
	Eel River	8	3,753,105	1
	Total	10	4,493,654	**2**
Mattole River	Mattole River	0	232,295	**0**
Ten Mile & Navarro River	Noyo River	1	100,417	0
	Navarro River	0	208,868	0
	Total	0	309,285	**0**
Russian River	Russian River	19	183,106	**17**
Santa Cruz	San Gregorio-Pescadero[1]	5	25,119	0
	San Lorenzo-Soquel	5	104,124	2
	Pajaro	15	60,475	6
	Total	12	189,718	**3**
Southern Monterey Bay	Salinas	19	488,734	**33**
Carmel River	Carmel	40	32,265	**59**
Pt. Sur & Morro Bay	Little & Big Sur Rivers[2]	3	179,388	**0**
Santa Maria	Arroyo Grande	46	37,325	67
	Santa Maria River	61	260,763	68
	San Antonio Creek	0	60,290	0
	Total	54	358,378	**64**
Santa Ynez	Santa Ynez River	47	347,078	**51**
Santa Barbara	Santa Ynez Mtn streams[3]	2	195,109	0
	Ventura River	37	102,252	53
	Santa Clara River	37	1,193,102	27
	Calleguas Creek	6	64,932	0
	Total	27	1,555,395	**26**
Santa Monica	Malibu Creek[4]	62	23,805	55
	Santa Monica Mtn streams[4]	0	43,332	0
	Ballona Creek[3]	7	2,890	0
	Total	23	70,027	**26**
San Pedro	LA River	54	77,187	67[5]
	San Gabriel	85	59,246	67[5]
	Santa Ana River	93	125,315	67[5]
	San Diego Creek	8	16,208	0
	Total	79	277,957	**66**

Oceanside	San Juan-Aliso Creek[2]	5	39,875	0
	Santa Margarita River	51	39,877	31[5]
	San Luis Rey River	39	39,907	69
	San Dieguito River[5]	89	12,508	79
	Total	44	132,166	**54**
Mission Bay	San Diego River[5]	63	6,581	**91**
Silver Strand	Tijuana River[5]	64	42,100	**49**
Total		38	11,079,954	**26**

[1] San Gregorio Creek and small Santa Cruz mountain stream inputs from Best and Griggs, 1991

[2] Big Sur River, Little Sur River, and Aliso Creek estimates from DNOD, 1977

[3] Inman & Jenkins, 1999

[4] Knur, 2001

[5] Brownlie and Taylor, 1981

The cumulative effect of these coastal dams has been to reduce the average annual sediment supply by more than 25% to California's 20 major littoral cells. Half of California's littoral cells currently receive less than two thirds of historical fluvial sediment supplies. In Southern California, (Point Conception to San Diego), sediment supply to the coast has been reduced by over 50% to half of the littoral cells; in the other half, reductions range from 26% to 49%. The greatest decrease in fluvial sediment delivery has occurred in the areas with the greatest demand for recreational beaches.

7.2.3 Sediment Impounded in Selected Reservoirs

Some of the effects of sediment impoundment by dams in the coastal watersheds of Southern California have been documented or predicted in studies by Brownlie and Taylor (1981), Griggs (1987), Inman (1989), Flick (1993), Inman and Jenkins (1999), and Barron (2001). The previous section predicted transport rates downstream of dams in coastal watersheds in California. These predictions are based on stream discharge records. To complement those model estimates, we have collected sedimentation data for several of those reservoirs based upon empirical data.

Sedimentation rate data were obtained for fourteen reservoirs/dams in Central and Southern California (Figure 7.9). The dams were selected based upon the size of the undammed drainage basin that they control (at least thirty square miles), proximity to the coast (less than thirty miles from the ocean), and the availability of data. The dams included are Los Padres and San Clemente Dams in Monterey County; Bradbury (Lake Cachuma) and Twitchell Dams in Santa Barbara County; Matilija and Santa Felicia (Lake Piru) Dams in Ventura County; Big Tujunga, Devil's Gate, Hansen, Puddingstone, San Gabriel, Santa Fe, and Sepulveda Dams in Los Angeles County, and Prado Dam in Riverside County.

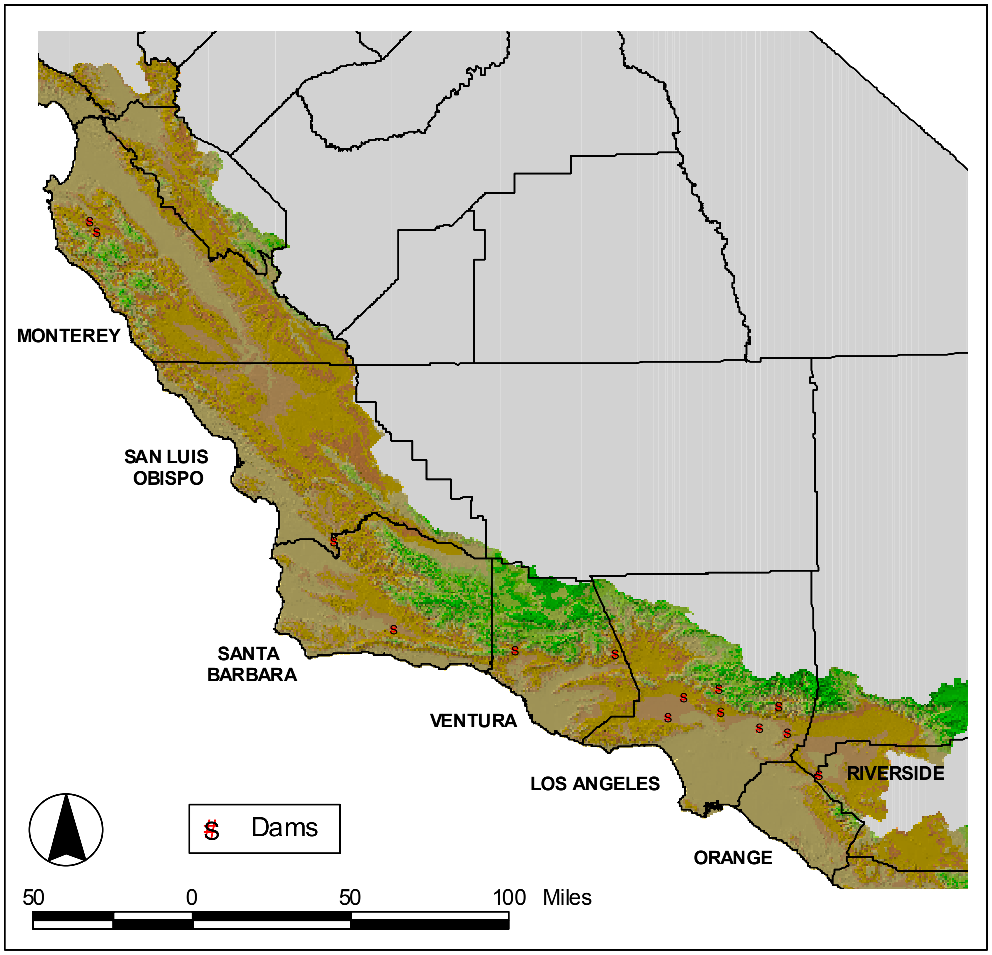


Figure 7.9 Distribution of the fourteen dams for which sedimentation rate data are presented
(Individual dams are identified in Appendix A)

The dams listed above reduce sediment delivery to the coast substantially. Summing the longest-term sedimentation rates for each of the fourteen dams (Table 7.3), it appears that the collective impact has been a total impoundment of about 273 million cubic yards of sediment, or an average impoundment rate of 5,990,000 cubic yards of sediment per year. Some of this sediment is in the size range commonly found on California beaches. However, most of the sediment is too fine or too coarse to be considered beach quality. For example, at Twitchell Reservoir, almost all of the 1,730,000 cubic yards of sediment trapped per year is too fine to remain on beaches. Taylor (1981) reports that sediments trapped in Lake Piru, behind the Santa Felicia dam in Ventura County, have a sand content (mean grain diameter larger than 0.062 mm and smaller than 2.00 mm) of about 20%. Taylor also suggests that the typical sand content of sediments trapped in the reservoirs in Santa Barbara and Ventura counties is about 20% (based mainly on the Lake Piru data), and, for the reservoirs in southern Los Angeles and Riverside Counties, sand content is about 50%. The contribution of the Monterey County reservoirs to the total impoundment rate is relatively small. For these reservoirs, we assumed 20% sand content as a conservative estimate. Applying these sand content data to the calculated impoundment rate for these reservoirs of 5,990,000 cubic yards per year, we obtain an estimated sand impoundment rate of about 1,330,000 cubic yards per year. Based on this analysis, about 90% of this sand (1,160,000 cubic yards per year) is trapped behind three structures: Hansen Dam and San Gabriel Dam in Los Angeles County, and Prado Dam in Riverside County.

Table 7.3 Sedimentation Rates in Selected Reservoirs

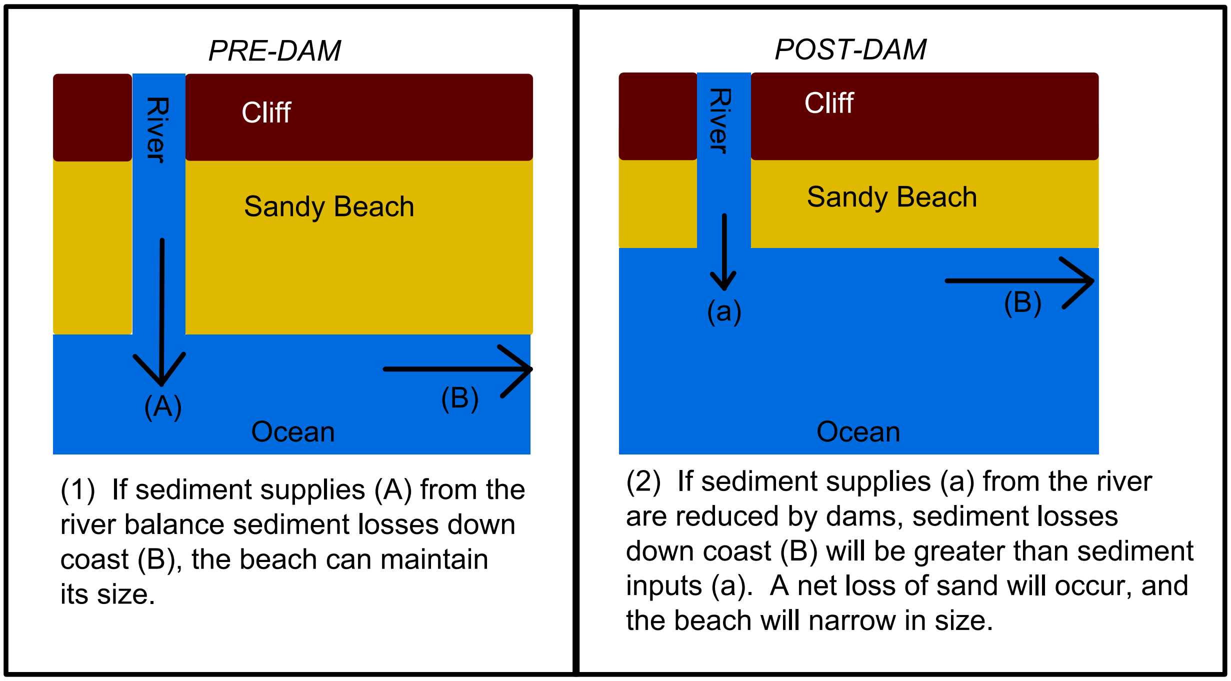
Dam	County	Watershed	Purpose*	Year Built	Period of Record	Sedimentation Rate (yd^3/yr)
Los Padres	Monterey	Carmel	water sup	1949	1949-2000	30,000
San Clemente	Monterey	Carmel	water sup	1921	1921-1996	30,000
Bradbury	Santa Barbara	Santa Ynez	water sup	1953	1953-2000	580,000
Twitchell	Santa Barbara	Santa Maria	water sup, flood con	1958	1958-1999	1,730,000
Matilija	Ventura	Ventura	water sup	1947	1947-1999	200,000
Santa Felicia	Ventura	Santa Clara	water sup, rec	1955	1955-1996	500,000
Big Tujunga	Los Angeles	Los Angeles	water sup, flood con	1931	1931-1982	230,000
Devil's Gate	Los Angeles	Los Angeles	water sup, flood con	1919	1919-1982	120,000
Hansen	Los Angeles	Los Angeles	flood con	1940	1940-1983	420,000
Puddingstone	Los Angeles	San Gabriel	flood con, rec	1925	1925-1980	50,000
San Gabriel	Los Angeles	San Gabriel	water sup, flood con	1932	1937-1983	77,000
Santa Fe	Los Angeles	San Gabriel	water sup, flood con	1943	1943-1982	200,000
Sepulveda	Los Angeles	Los Angeles	flood con	1941	1941-1980	trivial
Prado	Riverside	Santa Ana	flood con, rec	1941	1941-1979	1,130,000

* water sup = water supply; rec = recreation; flood con = flood control

From a sediment budget perspective, coastal dams can disrupt the long-term balance of sediment gains and losses to the coast, tipping the balance toward a long-term net loss of sand (Figure 7.10). Since fluvial sediment deliveries account for 70 to 90% of beach sand in California (Bowen and Inman, 1966; Best and Griggs, 1991), beaches can be expected to diminish in size if dams significantly reduce sediment supplies, such as in the 10 littoral cells that have experienced sediment reductions by 33% or more. To date, there have been no comprehensive studies to determine if long-term beach loss is occurring in California. However, there are many well-documented beach erosion "hot spots," including the Ventura County coastline, Malibu and the northern San Diego County coastline, that have been attributed qualitatively to dams by a number of sources (e. g. Noble Consultants, 1989; Capelli, 1999).

Artificial nourishment in Southern California kept pace with sediment losses from dam construction during the twentieth century (Flick, 1993). As large harbors were excavated and other large construction projects were undertaken (e.g. San Onofre Generating Station) along

Southern California between 1940 and 1960, over 130 million cubic yards of sand were placed on the region's beaches (Flick, 1993). However, by the late 1960's, harbor construction and the associated nourishment activities were curtailed. In some areas, the nourishment activities built beaches that were larger than previously maintained by the natural system. In other areas, the nourishment simply offset sand losses caused by dams. In short, beach nourishment has been a short-lived engineering solution to a long-term engineering problem: sediment impoundment by dams.



(1) If sediment supplies (A) from the river balance sediment losses down coast (B), the beach can maintain its size.

(2) If sediment supplies (a) from the river are reduced by dams, sediment losses down coast (B) will be greater than sediment inputs (a). A net loss of sand will occur, and the beach will narrow in size.

Figure 7.10 Potential impact of dams on long-term beach size

7.3 Debris Basins

7.3.1 Impact of Debris Basins on Sediment Supply

Debris basins are small catchments designed to trap coarse sediments while allowing the passage of water and fine sediments. Of principal concern in the location and design of these basins is the reduction of hazard posed by debris flows. A debris flow (commonly referred to by non-specialists as a "mud flow") is a form of slope failure where flood waters entrain large concentrations of unconsolidated, coarse sediments and flush them downstream at velocities that may approach 100 miles per hour. The sediment load in debris flows increases their density well above that of clear water, and thereby increases their potential to produce damage. Debris basins reduce the debris flow danger to the extent that they are able to trap the material being transported.

Debris basins are created by the construction of dams across intermittent or ephemeral stream channels, and they have typical capacities between 1,000 and 500,000 cubic yards. Plate 7.1 shows part of the La Tuna Canyon debris basin, located in Los Angeles County. The dam is earthen, with a concrete spillway to accommodate large discharge events. The tower at the base of the spillway is a drain that allows water and fine sediments to pass through its holes and continue downstream past the dam. In many debris basins, these vertical drains display markers that serve as indicators of basin capacity vis-à-vis the surface elevation of sediment deposits. Such markers are typically used to indicate when a basin should have its sediment deposits removed. Sediment removal is routinely required in order to maintain a basin's protective function.

Plate 7.1 The La Tuna Canyon debris basin (Photograph courtesy of K. Barron)

Debris basins have been used extensively in Southern California to reduce the magnitude of debris flows that threaten life and property in developed areas. Indeed, the majority of the debris basins in California have been built around the perimeter of the Los Angeles Basin, in watersheds in the San Bernardino, San Gabriel, Santa Monica, and Santa Susana Mountains, and most of the remaining are found in neighboring Ventura and Orange Counties (Figure 7.11). These mountains frequently produce large debris flows that often have been quite damaging (Troxell and Peterson, 1937). There are three factors that influence the generation of debris flows in this region: climate, relief, and fire. First, the local climate is characterized by relatively long periods of below-average rainfall, punctuated by extreme rainfall events (discussed in the context of slope failure by Cooke 1984). The periods of low rainfall allow sediments produced by dry erosion (dry ravel) to accumulate on slopes and at the bottoms of gullies and ravines because there is insufficient runoff to wash them downslope. The intense rainfall events are capable of generating stream discharges that are able to quickly mobilize large volumes of the stored sediments.

Second, steep slopes also are important for producing debris flows. Such slopes enhance the transport of dry ravel into the beds of ravines, where it is then stored until flooding flushes it downstream. Other forms of slope failure (e.g., soil slips and landslides) also are common on steep slopes, and these processes contribute to the delivery of unconsolidated sediments into ravines. Such failures, often rainfall-induced, may be a direct triggering mechanism for the generation of a debris flow. Further, steep slopes are likely to produce substantial and rapid surface runoff for a given rainfall event. According to Campbell (1975), most debris flows in Southern California occur on slopes with angles between about 27^o and 45^o.

Third, the destruction of hill slope vegetation by wild fire increases the likelihood of debris flow generation. In the aftermath of a brush fire, there is an increase in sediment production and runoff from hill slopes in Southern California. Runoff is increased because the removal of vegetation reduces interception of precipitation and decreases transpiration. Further, infiltration rates in post-fire soils are usually slower than the antecedent condition. Sediment delivery is increased because of physical changes in soil characteristics and because the post-fire soil surface is exposed to direct erosion by rain splash and overland flow. These processes may increase sediment production from steep slopes by as much as two orders of magnitude (Wells, 1981). According to Ferrell (1959), erosion rates in the first year after a fire may be twenty times larger than those under normal conditions. Wells and Brown (1982) described such effects as persisting as long as a decade after a burn, although the impacts diminish throughout that period.

These three factors commonly are present in the mountains surrounding communities in Southern California. Debris flows have caused some of the most deadly natural disasters in Southern California history. The 1934 debris flow that devastated Montrose and adjacent communities may have killed nearly one hundred people (many of the victims were missing) – equivalent to the death toll from the Northridge earthquake in 1994 (e.g., Davis 1998). The threat of future catastrophic debris flows persists in California’s coastal mountain ranges, and the magnitude of threat is probably increasing because development continues in hazardous locations.

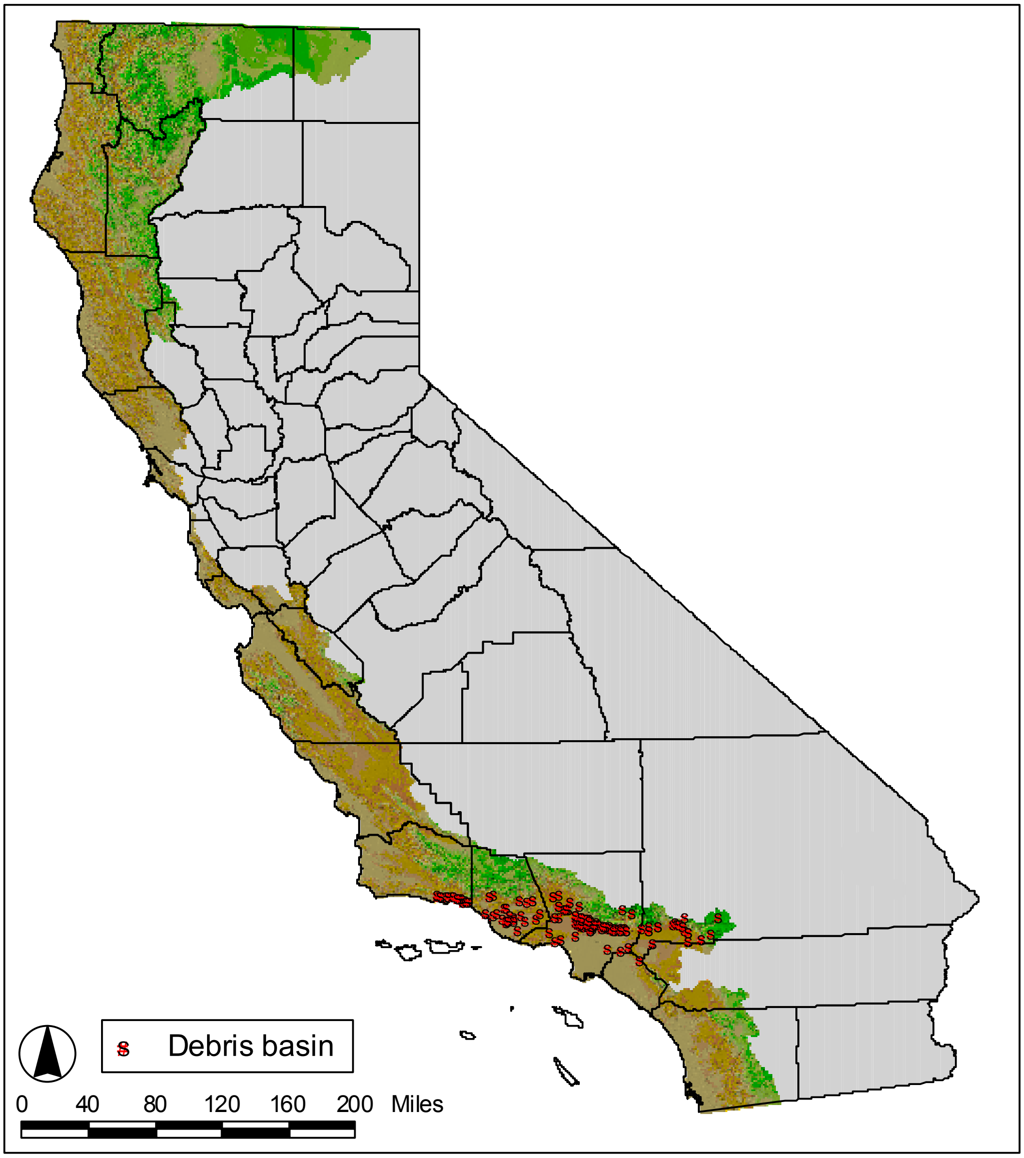


Figure 7.11 Distribution of debris basins in coastal watersheds in California.

7.3.2 Sediment Impoundment in Debris Basins

Debris basins are designed to trap sediments of sand size and larger, and they are generally quite successful in this endeavor. However, in accomplishing their design function, these basins also interrupt the movement of sediments from the mountains toward the coast. Sediment storage within debris basins degrades their utility. Therefore, agencies charged with basin maintenance have developed cleanout protocols. For example, the Los Angeles County Department of Public Works (LACDPW) has a protocol based upon loss of storage volume and fire history. According to Bohlander (personal communication cited in Barron 2001), a debris basin that is located in a watershed that has not been burned in the preceding four or five years will be allowed to lose about 25% of its capacity before normal maintenance cleanout is scheduled. In recently burned watersheds, cleanout occurs when 5% of the capacity is lost. In 2000, the drain (outlet) towers in LACDPW debris basins were marked with lines indicating the 5% and 25% capacity loss elevations to simplify estimation of debris volumes and to aid in recognition of basins where cleanout is appropriate. Most agencies keep records of cleanout projects that include volume of material removed. These data constitute a valuable record of sediment impoundment.

Kolker (1982) found that, as of 1978, a total of about 13,692,300 cubic yards of sediment had been removed from more than 100 debris basins in coastal watersheds in Ventura, Los Angeles, San Bernardino, Riverside, Orange, and San Diego Counties (although the latter two counties had few debris basins and no record of sediment removal). The number of debris basins included in that study cannot be determined because data for San Bernardino County were reported by watershed rather than by basin. Further, the length of time over which removal had occurred varied from county to county, and also depended on the age of individual debris basins. There is minimal information concerning the sediment grain size characteristics of these deposits. Therefore, the fraction of these deposits that lies within the sand size range is unknown. However, according to the work of Taylor (1981), it would not be unreasonable to assume that about 50% of these sediments are in the sand size range. Thus, through 1978, approximately 7,000,000 cubic yards of sand had been removed during the cumulative life spans of the debris basins in the counties listed above. It is presumed that little of this sand was returned to the drainage system, and therefore this removal ultimately represents a loss of sand from the coastal sediment budget.

7.3.3 Inventory of Debris Basins in Coastal Watersheds

We identified 194 debris basins in Santa Barbara, Ventura, Los Angeles, San Bernardino, and Riverside Counties (Figure 7.12). Data for these debris basins are presented in Appendix B. For Santa Barbara County, data collected through June 1998 were produced by the Santa Barbara County Flood Control & Water Conservation District and Water Agency. For Ventura County; the data source is the *Detention Dams & Debris Basins Manual*, prepared by the Hydrology Section of the Ventura County Flood Control District, as revised in June 1999. Data for Los Angeles County through the 1999-2000 storm season were provided through personal communication with Mr. Mike Bohlander, head of the Hydrologic Engineering Section of the Los Angeles County Flood Control District. Data for San Bernardino County were provided through personal communication with Mr. Tony Wimenta, Flood Control Zone Coordinator at the San Bernardino Department of Public Works. Data for Riverside County were provided through personal communication with Mr. Mike Biloki of the Riverside County Flood Control District.

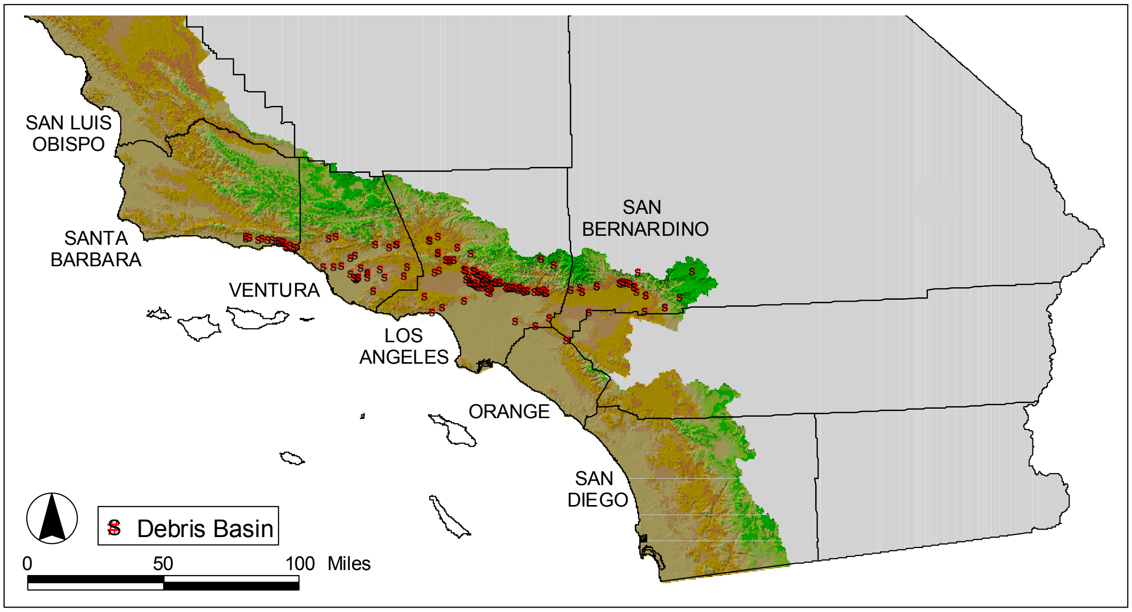


Figure 7.12 Distribution of debris basins in coastal watersheds in Southern California.

We were unable to locate quantitative data for purpose-built debris basins (that is, designed specifically to reduce debris flow speed and/or volume) in any other California counties. Additionally, we were not able to collect data for the many small structures and basins designed to retain small amounts of sediment (<1,000 cubic yards), usually to protect roads or prevent clogging of culverts or pipes. We were unable to obtain quantitative data on sediment accumulation and sediment removal for the 33 debris basins located in San Bernardino County. These basins are distant from the coast. For these reasons, the San Bernardino debris basins are not considered further in this report.

As of 2000, the 162 basins for which accumulation data were acquired (listed in the "Total Debris Deposited" column in Appendix B) trapped more than 18,000,000 cubic yards of debris over their cumulative periods of operation. About 17,600,000 cubic yards of debris have been removed in maintenance operations to preserve the capacity of the basins. Applying Taylor's (1981) estimate of 50% sand content to these deposits, these basins have trapped and had removed about 9,000,000 cubic yards of sand. Very little of the removed sediment is delivered directly to local beaches or returned to fluvial systems for eventual transport toward the coast (Barron, 2001).

Despite the relatively large net trapping effect of the debris basin population, the overall effect of individual structures is usually small. For example, 95 of the basins have each trapped less than 50,000 cubic yards of debris in total. Again using the Appendix B data, we can divide "Total Debris Deposited" by the age of a basin to determine average annual deposition rates. This process reveals that only 82 of the 162 basins have average sedimentation rates exceeding 1,000 cubic yards per year. Only 13 basins (listed in Table 7.4) have average sedimentation rates exceeding 10,000 cubic yards per year. If the assumption of 50% sand content is applied, only three of the basins – Little Dalton, Big Dalton, and Santa Anita – intercept more than 10,000 cubic yards of sand per year.

Table 7.4 Debris Basins with Average Deposition Rates Exceeding 10,000 yd^3/year

DEBRIS BASIN	COUNTY	DEPOSITION RATE (YD^3/YR)
LITTLE DALTON	Los Angeles	22,643
BIG DALTON	Los Angeles	20,951
SANTA ANITA	Los Angeles	19,261
SIERRA MADRE VILLA	Los Angeles	18,221
SAWPIT	Los Angeles	15,228
LA TUNA	Los Angeles	14,750
VERDUGO	Los Angeles	12,738
GABBERT CANYON	Ventura	11,376
ADAMS	Ventura	11,271
PICKENS	Los Angeles	11,246
LIMEKILN	Los Angeles	10,917
ARUNDELL BARRANCA (OLD)	Ventura	10,888
ALISO	Los Angeles	10,003

The rates of debris interception by basins are highly irregular through time and space. The temporal distribution of severe rainstorms and the spatial and temporal distribution of fires make debris production forecasting difficult. Further, most of the debris accumulation data reported in the table above and in Appendix B are strongly influenced by one or two years of extreme data. These effects can be illustrated through an examination of data for debris basins in the Los Angeles River and San Gabriel River watersheds in Los Angeles County (Figure 7.13), based on the work of Barron (2001).

The combined capacity of the 85 debris basins in the Los Angeles River watershed totals 5,813,250 cubic yards, while the total for the 21 Basins in the San Gabriel River is 1,780,600 cubic yards. The average capacity of basins in the Los Angeles River drainage is about 68,000 cubic yards, and 85,000 cubic yards for the San Gabriel River drainage. As of 1997, the 85 debris basins of the Los Angeles River have experienced a combined number of storm seasons that totals 3,091 seasons (or years), or about 30 seasons per basin. Those in the San Gabriel River watershed combine for 620 seasons, or about 15 seasons per basin. Debris basins in the Los Angeles River watershed annually trap about 6,000 cubic yards of sediment per square mile of drainage area. The analogous rate for the San Gabriel River watershed is approximately 5,600 cubic yards per year per square mile. The basins of the Los Angeles River watershed each capture an average of about 3,200 cubic yards of sediment annually, and each basin in the San Gabriel River watershed capture nearly 3,400 cubic yards annually.

Figure 7.13 Distribution of debris basins in Los Angeles County in 1997.

A number of studies (e.g. Inman and Jenkins 1999) have indicated that, in Southern California, extreme precipitation events are responsible for sediment production that greatly exceeds average conditions. This can be seen in LACDPW data for maximum debris production years for its debris basins (Figure 7.14).

These maximum debris production events are closely associated with the large flooding events identified as peak episodes during wet periods by Inman and Jenkins (1999). Their study stated that this region experienced a dry period from 1944 to 1968 that was followed by a wet period from 1969 to 1995. Sediment yield increased with the number of dry, or low-flow, years that preceded a wet-year event due to the build-up of sediment within the watersheds (Inman and Jenkins, 1999). Most importantly, transport of sand-sized sediment, as opposed to clay or silt, escalated as streamflow increased.

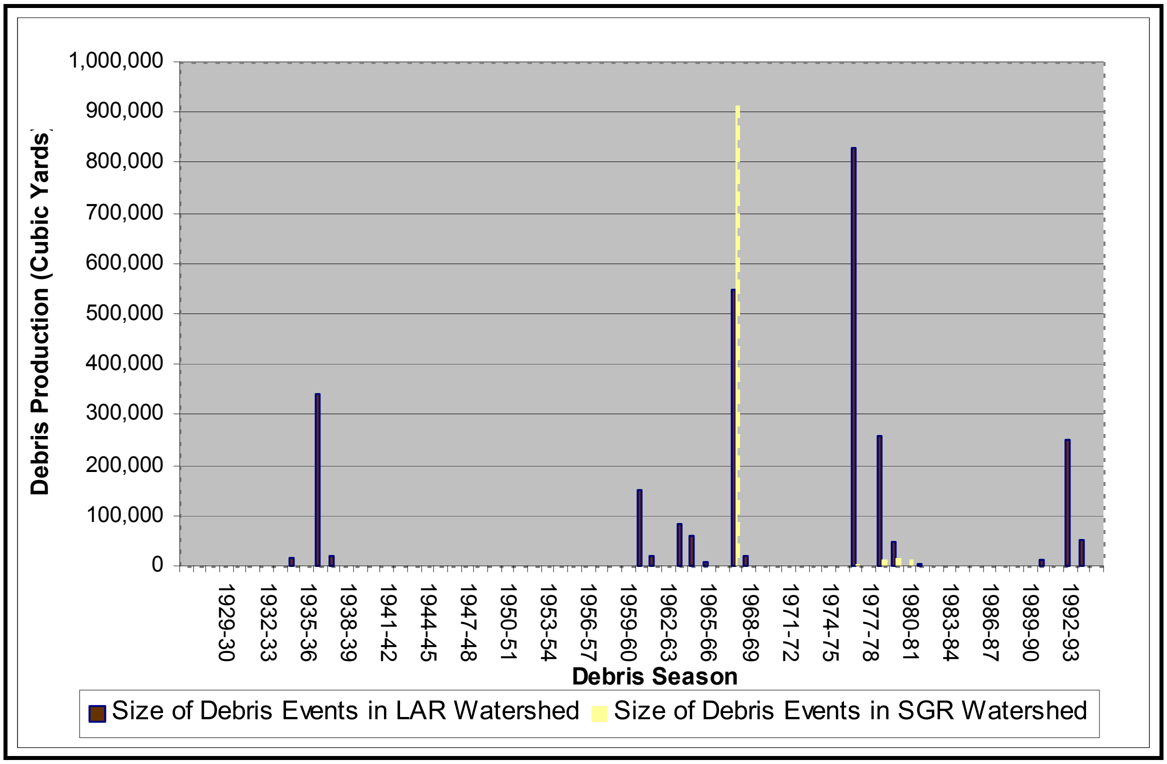


Figure 7.14 Distribution of maximum debris-producing events in the watersheds of the Los Angeles River (LAR) and the San Gabriel River (SGR)

Inman and Jenkins (1999) noted that the Los Angeles River had its highest yields of suspended sediment in 1969, 1978 and 1983, respectively, all during wet periods (Inman and Jenkins, 1999). Two of these years, 1969 and 1978, also had substantial accumulation of sediments in debris basins. The 1983 storm year may not have had significant sediment yield because it followed the 1978 storm that would have flushed much of the available sediment from the fluvial system.

The temporal distribution of maximum debris producing years is shown in Figure 7.14. The figure indicates the combined debris accumulation for the basins experiencing their maximum events in a particular year. For the Los Angeles River system, it can be seen that there are small peaks during the late 1930s when more than 350,000 cubic yards of sediment were deposited. These events were larger than the raw numbers might indicate because this trapping was accomplished by only 16 debris basins. These years represent the maximum debris production year for most of those sixteen basins. There also are noticeable peaks during the 1968-69 season (a maximum for 10 debris basins: 546,400 cubic yards deposited) and the 1977-78 season (a maximum for 27 debris basins: 829,855 cubic yards deposited). A small peak also occurred in the early 1990s; more than 300,000 cubic yards of sediment were deposited between late 1991 and early 1995. In terms of the quantity of debris production, 1978, 1969 and 1938 had the greatest sediment accumulation, respectively. Two of these three years matched maximum suspended sediment flux/yield years identified by Inman and Jenkins (1999). Debris was produced throughout the 1960s, prior to the 1969 onset of the wet period that was identified by Inman and Jenkins (1999).

Inman and Jenkins (1999) found that the greatest suspended sediment yields for the San Gabriel River occurred in 1983, 1980 and 1969. The 1968-69 debris season produced the greatest amount of sediment deposition, totaling 912,900 cubic yards for half of the 18 debris basins that reported a maximum debris year. This could be considered a "first flush" event that removed sediment that had accumulated for decades during the dry period (Inman and Jenkins, 1999). The remaining maximum debris events were spread from late 1977 to early 1982. Two of the three maximum debris accumulation years matched Inman and Jenkins' (1999) maximum sediment yield years for the San Gabriel River.

According to Barron (2001), maximum debris accumulation years in the Los Angeles River system accounted for about 2,719,000 cubic yards of the total basin accumulation of 11,752,000 cubic yards. This means that 23% of all accumulated debris was trapped during a maximum year. A normal seasonal deposition for a single basin is about 2,500 cubic yards in the Los Angeles River watershed, but the average for a maximum debris production year is about 34,000 cubic yards. Of the total of nearly 2,555,000 cubic yards deposited in the basins of the San Gabriel River watershed, 931,200 cubic yards (36%)were deposited during the maximum years. A normal seasonal deposition for a single basin is about 2,400 cubic yards in the San Gabriel River watershed, but the average for a maximum debris production year is about 52,000 cubic yards.

7.4 Channelized Streams

7.4.1 Impact of stream channelization on sediment supply

By definition, a stream is channelized when its bed has been straightened, smoothed or deepened to permit the faster flow of water (Bates and Jackson, 1984). In urbanized watersheds, rivers and streams are channelized for two key reasons: flood control and stream bank stabilization. Many studies have shown that urbanization produces a pronounced effect on flood hydrographs (Figure 7.15): the lag time between peak rainfall intensity and peak runoff decreases, the magnitude of flood peaks increase, and there is an increase in total runoff volume (Mount, 1995). The primary goal of stream channelization in urbanized watersheds is to disperse runoff from impermeable surfaces in a city as quickly and efficiently as possible in order to help prevent flooding (Mount, 1995).

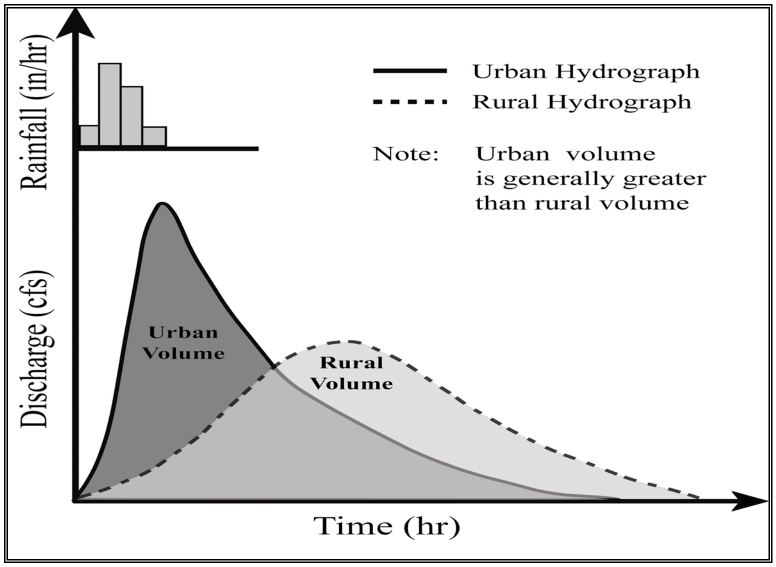


Figure 7.15 Hydrograph of urbanized watershed compared to rural watershed (From Mount, 1995)

Channelization in highly urbanized areas may take the form of excavation of streambeds and lining them with concrete (Plate 7.2) or spraying them with gunnite in order to decrease roughness. This increases flow velocities and impedes both downward and lateral erosion common to earthen (soft-bottom) channels (Mount, 1995). According to various researchers (Lane, 1937; Shen, 1971a; Richards, 1982), in order for an artificial channel excavated in natural sediment to remain stable, it must be able to transmit a bankfull discharge without experiencing bed or bank erosion (scour) or deposition of any sediment load from upstream. Often, this is not the case, and earthen channels tend to be unstable over time.

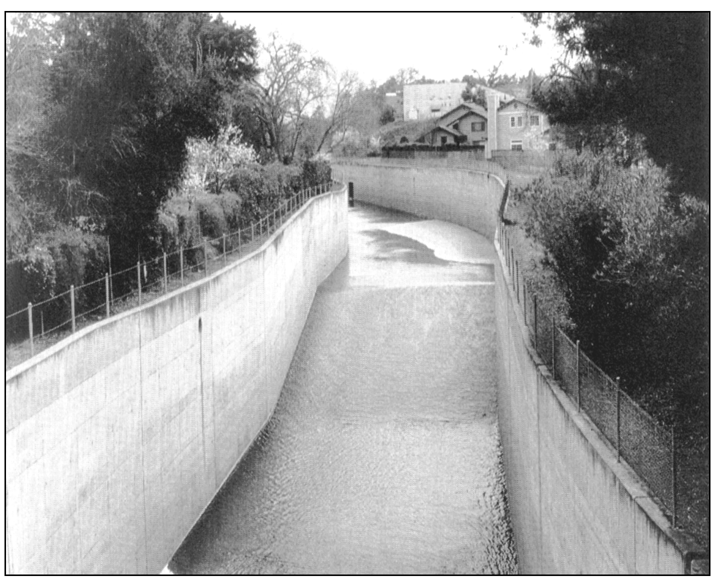


Plate 7.2 A channelized stream, deepened and lined with concrete (from Mount, 1995)

When artificial channels cannot transport the sediment load introduced upstream, deposition occurs within the channel and, in some cases, must be excavated. A concrete channel full of sediment is more prone to backup and flooding than an empty channel due to material slowing and disrupting the flow of water. This problem occurs in the county of Los Angeles, where the Department of Water and Power (LADWP) maintains 460 miles of channels (Plate 7.3). During the fiscal year of 1998 – 1999, the LADWP excavated 13,190 tons of sediment that had accumulated in their channels, and during the fiscal year of 1999 – 2000, they removed 43,809 tons of sediment (Table 7.5). The total amount of sediment removed varies greatly over time, but unfortunately these are the only two years for which the LADWP has accurate records as 1998-99 was the first year the department began using a computerized maintenance management system to track their work (personal communication – Jerry Burke, LADWP, Flood Maintenance Division).

Plate 7.3 *Los Angeles River flowing in a concrete channel* (from Mount, 1995)

Hard bottom channels not only are susceptible to problems of sediment deposition and removal, but also they prevent the downward and lateral erosion that naturally can supply beach-size material to the shoreline. Trimble (1997) found that stream channel erosion in San Diego Creek, which drains a 111 mile^2 (288 km^2) watershed in Orange County, has furnished about two-thirds of the total sediment yield, or 110,231 tons (100,000 tonnes) per year of sediment into Newport Bay. If this is the case for many Southern California streams and rivers, then constructing hard bottom channels cuts off an important supply of sediment to the coast.

Table 7.5 Summary of Stream Channelization and Channel Dredging in California

County	number of channelized streams	length of channelization in streams (miles)	volume of sediment removed from littoral system by channel excavation (yd^3/yr)
Del Norte	0	0	0
Humboldt	0	0	0
Mendocino	n.d.	n.d.	n.d.
Sonoma	1	n.d.	n.d.
Marin	3	n.d.	n.d.
San Francisco	n.d.	n.d.	n.d.
San Mateo	n.d.	n.d.	n.d.
Santa Cruz	2	4	n.d.
Monterey	n.d.	n.d.	n.d.
San Luis Obispo	n.d.	n.d.	n.d.
Santa Barbara	At least 4	n.d.	n.d.
Ventura	n.d.	n.d.	In 1978: 208,946 yd^3
Los Angeles	n.d.	460	Fiscal Year 1998-99: 10,782 yd^3 Fiscal Year 1999-00: 35,812 yd^3
Orange	Incomplete Data	n.d.	From 1972-77: 1,208,782 yd^3
San Diego	Incomplete Data	n.d.	n.d.

- *n.d. indicates no data were obtained.*
- *Information was provided at the county level, not the water-body level, so watersheds are undefined.*

7.4.2 Inventory of Stream Channels in Coastal Watersheds

In California, stream channelization in coastal watersheds is most relevant in the southern part of the state, where the population density is the greatest and the total length of channelized streams is the greatest. In Northern California, stream channelization is not an issue of concern due to lower population densities and a lack of large-scale urbanization.

Overall, the amount of information kept by county and city governments regarding the number of channelized streams within their jurisdiction, the length of channelization within those streams, the volume and grain size of sediment excavated and the final destination of that sediment is minimal. Workers in planning, engineering, public works, and flood control departments were contacted, or contact was attempted, for each coastal city and county. In many cases, replies were never made to phone messages or emails. When a contact was established, the contact often had no information or no time available to find the information requested. In some cases, contacts were very helpful; they searched for and supplied the data that were available (see Appendix C).

One reason that this investigation was largely unsuccessful in collecting data is that the organization of this information is at the county and city level. It appears that most local governments do not seriously track the removal of sediment from their channels. If local governments monitored and kept digital records of the sand content, average volume and final destination of excavated material, this investigation would have had greater success.

Given the lack of data available regarding channelized streams and sediment extraction from the stream channels, it is difficult to make any assessment of the significance of the volume of sediment removed from the littoral sediment system by these practices. The minimal data available on sediment extraction from the Los Angeles River channels (Table 7.5) show that, during fiscal year 1999-00, the total amount of excavated material was equal to about half of the average annual sand discharge of the river (Section 7.1, this report). The results from Trimble's work on San Diego Creek (1997) further suggest that a detailed investigation into the extent of stream channelization and channel dredging in coastal watersheds is warranted in order to assess whether or not alterations to these practices could yield an increase in sediment supply to the coast.

7.5 Prioritizing Sites for Sediment-Supply Intervention

In littoral cells where the value of beaches is substantial, beach erosion represents a significant economic loss (King, 1999). Where such losses are of a magnitude to threaten local economies, intervention to mitigate erosion caused by reduction of sediment supply may be desirable or necessary. Human activities have reduced substantially the supply of sediment to many littoral cells along the coast of California, especially in the central and southern parts of the state. For example, in Section 7.2.3 it was shown that fourteen reservoirs in Central and Southern California impound approximately 1,330,000 cubic yards of sand per year. On average, another 90,000 cubic yards of sand are trapped in the thirteen most productive debris basins, as discussed in Section 7.3. In some of the cells affected by these reductions, direct action to enhance sediment delivery to the beach may be justified. A challenge to the implementation of such strategies is the identification and prioritization of potential sites where sediment supply intercession would be most efficient. This section outlines a sample protocol for the identification of reservoirs and debris basins that might be candidate sites for sediment transport intervention.

7.5.1 A Protocol for Reservoir Identification

We have developed a simple method for identifying reservoirs that represent reasonable candidates for the development and application of policies to mitigate their impoundment of sediment. Other, more complex methods of identifying dams for management intervention might incorporate the economics of sand transport and assessments of impacts to riparian habitat, for example, on a site-specific basis; the protocol used here is just one example of a dam-identification methodology. The process began with data originally obtained from the National Inventory of Dams (USACOE, 1996) that describe dams that are at least 25 feet high and store at least fifty acre feet of water. About 1500 dams in California meet these criteria (e.g., Graf, 1999). Approximately one third of these dams (497) are in watersheds that drain directly to the coast (this definition excludes drainage through the Central Valley, for example). Many of these dams control discharge from large watersheds, but their net drainage areas – the area above a dam that is uncontrolled by other, upstream structures -- may be much smaller. Because most reservoirs are very efficient sediment traps (Collier et al., 1996), it can be assumed that virtually all sediment delivery to a particular reservoir will originate within the net drainage area. For the purpose of identifying a short list of dams where sediment impoundment might be substantial, it was decided therefore to consider further only those dams with a net drainage area of at least 36 square miles. The data in Table 7.6 indicate that the highest sediment production rates in the systems considered are more than 1,400 cubic yards per year per square mile of drainage. Multiplying 36 square miles of net drainage by 1,400 cubic yards per square mile per year yields an annual impoundment rate of about 50,000 cubic yards per year for a reservoir of this size. It was expected, therefore, that drainage systems smaller than about 36 square miles would rarely produce sediments at rates exceeding this value (although exceptions do occur, such as Devil's Gate Dam in Los Angeles County). We adopted this as a minimum annual accumulation rate to target a reservoir for further attention because this rate should generate about 25,000 cubic yards of sand per year. It is believed that smaller amounts probably would not represent substantial impacts to most California littoral cells, although larger or smaller rates might be appropriate for some coastal reaches. From the list of 497 dams in coastal watersheds, 53 dams met the net drainage area criterion (Figure 7.16).

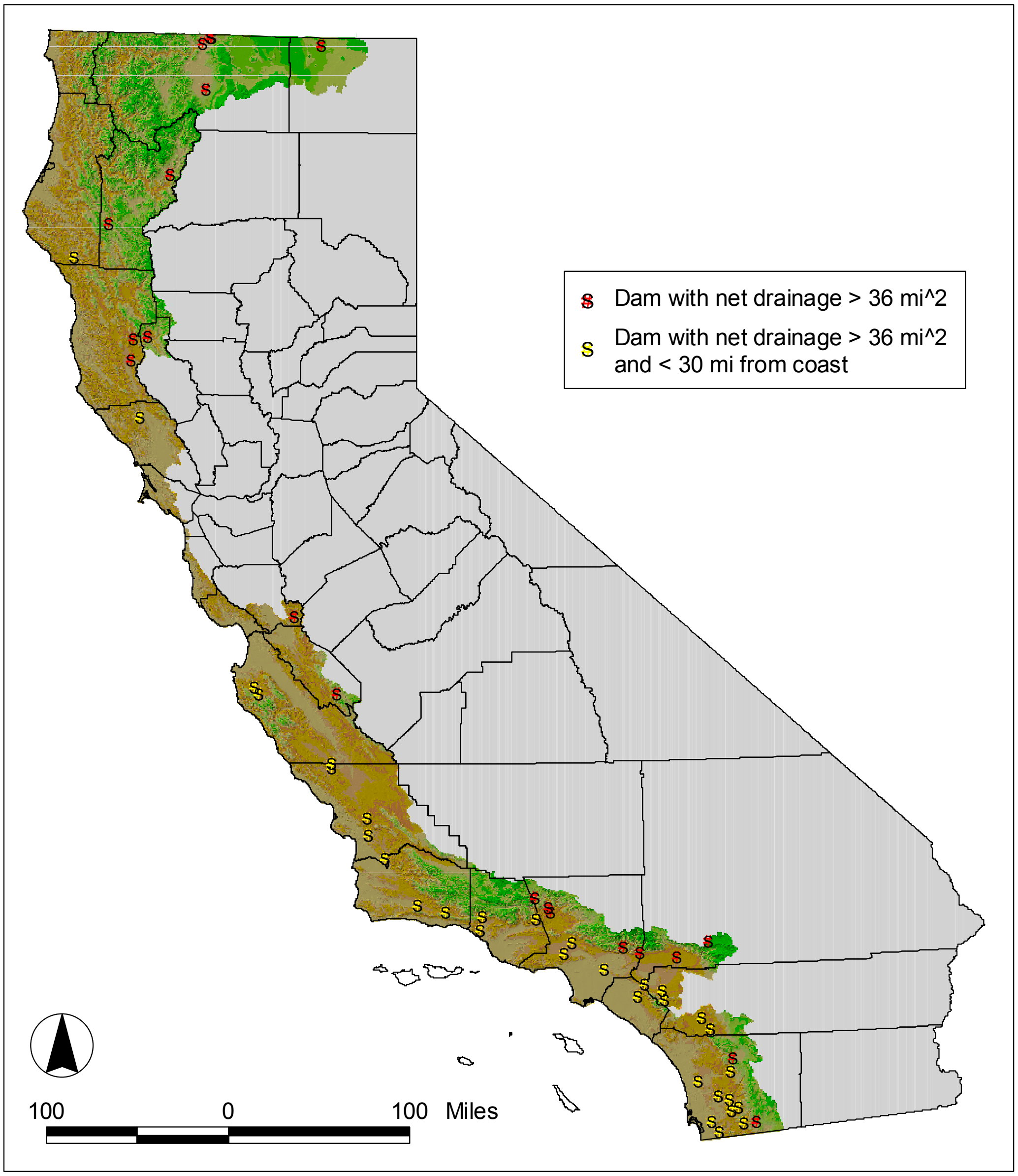


Figure 7.16 Locations of dams in California's coastal watersheds that control net drainage areas larger than 36 square miles

(Dams that are also less than 30 miles from the coast are highlighted)

Many of the 53 dams identified by the basin size criteria are far from the coast. Direct intervention in the sediment transport system, by physical movement of sediments via truck or sluice, for example, becomes economically impractical over long distances. We decided to apply a 30 mile limit to this distance. If a dam is located more than 30 miles from the coast, it was not considered further in this analysis. Larger or smaller distances may be appropriate cutoffs for some coastal reaches. Figure 7.17 shows the locations of the 53 dams that met the net drainage size criteria, and the subset of 32 dams that also met the distance-to-the-coast criterion.

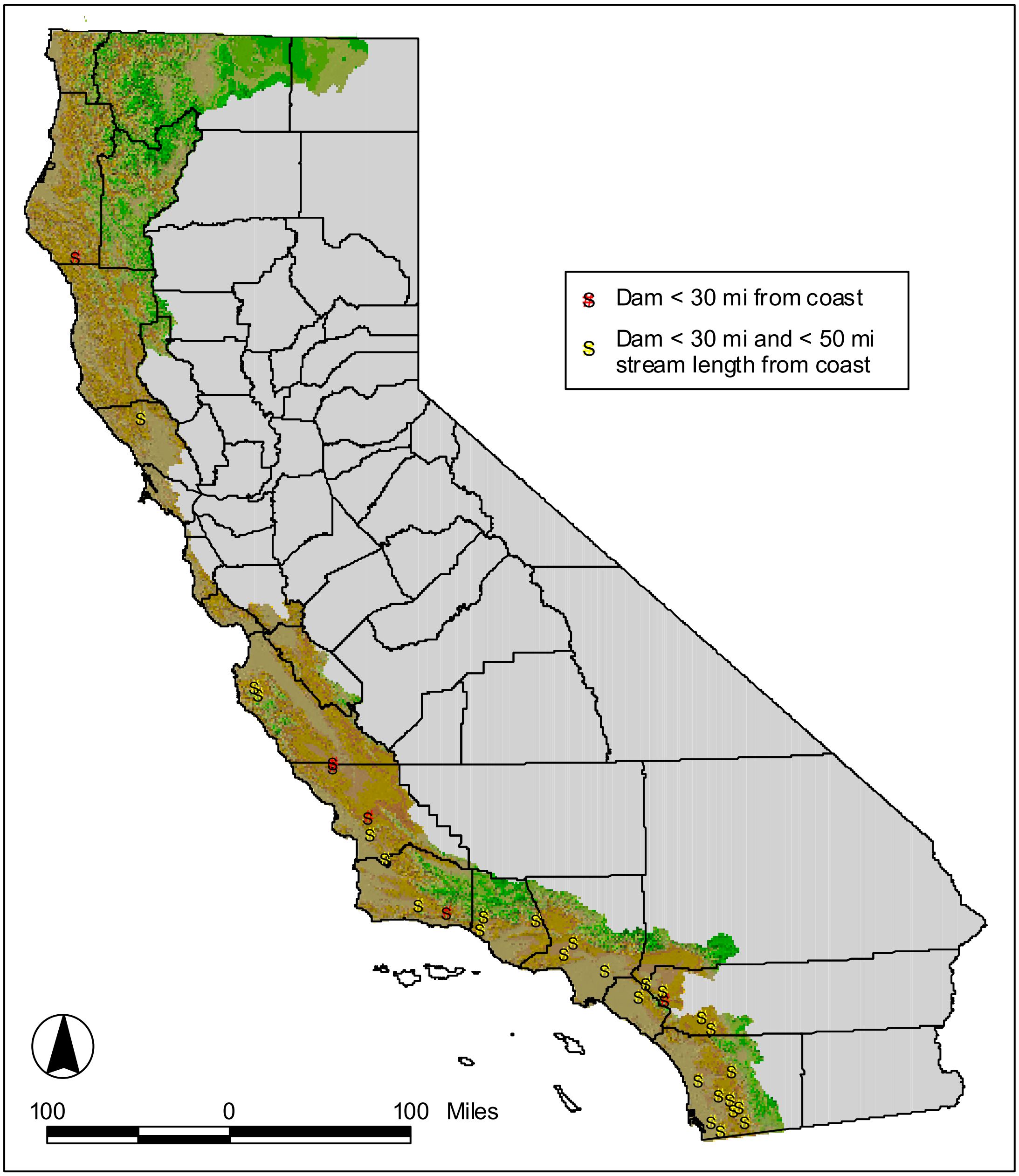


Figure 7.17 Location of dams with net drainage basins larger than 36 square miles, located less than 30 miles from the coast, with downstream channel lengths less than 50 miles

Another approach to restoring natural sediment supply is to partially or completely remove the impounding structure. Under some conditions, this approach may be the best solution to a number of complex environmental impacts associated with a particular structure (Task Committee on Guidelines for Retirement of Dams, 1997). However, we recognize that the release of sediments caused by dam removal (partial or complete) may have substantial and unpredictable negative impacts on downstream environments. Impacts include channel aggradation, changes in channel geometry and flow capacity, alteration of local habitat, and siltation (Hotchkiss et al., 2001). As a proxy for making river-specific impact assessments, given the lack of information needed to support such assessment, we assumed that the magnitude of the risk that substantial negative impacts would occur is related to the length of the fluvial system downstream of the dam being removed. Therefore, we applied a downstream distance criterion to the set of 32 dams described above. A dam was considered further only if the downstream distance separating the dam from the ocean is less than 50 miles. This procedure excludes dams such as Nacimiento and San Antonio that are located quite close to the coast when measured by straight line distance, but are well removed when measured by channel length. Figure 7.18 shows the locations of the 26 dams that meet all of the criteria described above.

The proximity to urbanized regions and the characteristics of the environment into which the respective fluvial systems drain were then examined for the remaining 26 dams. This review lead to the removal of another six structures from consideration: five in southern San Diego County, east of the City of San Diego (thus making physical transportation of sediments west to the coast through or around the city difficult), that also control drainage into San Diego Bay (where enhanced sediment delivery associated with sluicing or dam removal creates a sedimentation problem), and Warm Springs Dam, which controls drainage into the Russian River; the only beach in the vicinity of the mouth of the Russian River is a small barrier beach that does not appear to be at risk from erosion.

This method of prioritizing dams--in terms of their potential disruption of natural sediment transport processes and the ability to physically mediate the disruption--yields a set of twenty structures that may be suitable for sediment transport intervention. These structures and their characteristics are listed in Table 7.6. The locations of the structures are depicted in Figure 7.18.

This set of dams was then categorized according to the sedimentation data we obtained for each. Sedimentation data were not available for three of the dams: Casitas, Lopez, and Santiago Creek. Five of the dams exhibit minimal or no apparent sediment impoundment: Mathews, Robert A. Skinner, Sepulveda, Vail, and Whittier Narrows. The remaining twelve structures are priority sites for potential sediment transport intervention.

Table 7.6 Inventory of Dams Designated as Potential Priority Sites for Sediment Supply Intervention

(This designation is based solely upon net drainage basin size and distance from the coast.)

Dam	*County*	*Stream*	*Reservoir Capacity (yd^3)*	*Year of Last Survey*	*% Capacity Remaining*	*Sedimentation Rate (yd^3/yr)***
BRADBURY[1]	Santa Barbara	Santa Ynez River	330,665,000	2000	92%	580,000
CASITAS	Ventura	Coyote Creek	409,702,000	no data	no data	no data
EL CAPITAN[2]	San Diego	San Diego River	18,1946,400	1998*	96%	160,000
HANSEN[3]	Los Angeles	Tujunga Wash	41,044,398	1983	71%	420,000
LAKE HODGES[2]	San Diego	San Dieguto River	60,810,100	1994	91%	130,000
LOPEZ	San Luis	Arroyo Grande	84,682,500	no data	no data	no data
LOS PADRES[4]	Monterey	Carmel River	5,000,300	2000	67%	30,000
MATHEWS[5]	Riverside	Tr Cajalco Creek	293,566,000	n/a	100%	trivial
MATILIJA[6]	Ventura	Matilija Creek	2,903,400	1999	7%	200,000
PRADO[7]	Riverside	Santa Ana River	507,127,200	1996	86%	1,130,000
ROBERT A SKINNER[5]	Riverside	Tuucalota Creek	70,649,400	n/a	100%	trivial
SAN CLEMENTE[4]	Monterey	Carmel River	2,298,525	1996	10%	30,000
SAN VICENTE[2]	San Diego	San Vicente Creek	145,540,990	1998*	98%	40,000
SANTA FELICIA[8]	Ventura	Piru Creek	161,300,000	1996	87%	500,000
SANTIAGO CREEK	Orange	Santiago Creek	40,325,000	no data	no data	no data
SEPULVEDA[2]	Los Angeles	Los Angeles River	28,106,525	1980	100%	trivial
SUTHERLAND[2]	San Diego	Santa Ysabel	46,777,000	1998*	99%	10,000
TWITCHELL[1]	San Luis	Cuyama River	387,120,000	1999	71%	1,730,000
VAIL[9]	Riverside	Temecula Creek	82,263,000	n/a	100%	trivial
WHITTIER NARROWS[3]	Los Angeles	San Gabriel River	108,167,780	1977	97%	trivial

** preliminary survey data*
*** Method of calculating the sedimentation rate was not provided in source reports.*
[1] Source: Mr. Robert Wignot, General Manager, Cachuma Operation and Maintenance Board, 2001.
[2] Source: Ms. Rosalva Morales, Associate Engineer, City of San Diego Water Department, 2001.
[3] Source: Subcommittee on Sedimentation, 1992.
[4] Source: Mr. Andy Bell, District Engineer, Monterey Peninsula Water Management District, 2001.
[5] Source: Mr. Randy Whitney, Metropolitan Water District, 2001.
[6] Source: Mr. Charles Burton, Division Engineer, Ventura County Public Works Department, 2001.
[7] Source: Mr. Brian Tracy, Chief, Reservoir Regulation Section, U.S. Army Corps of Engineers, Los Angeles District, 2001.
[8] Source: Mr. Jim Kentosh, Senior Engineer, United Water Conservation District, 2001.
[9] Source: Mr. Craig Elithorp, Operations Manager, Ranch California Water District, 2001.

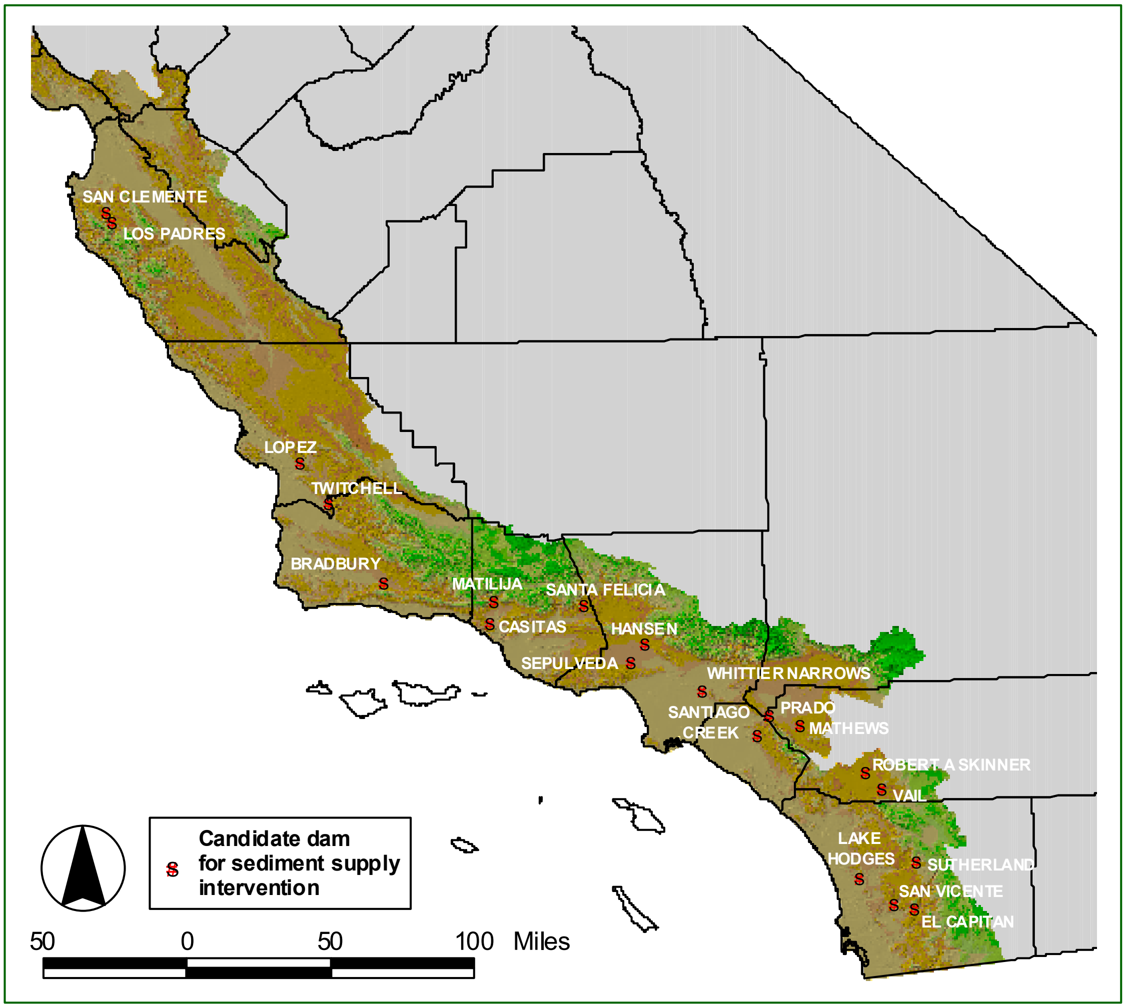


Figure 7.18 Location of dams of potentially high priority for sediment supply intervention

A dam is considered to impound a significant volume of sediment if its annual sedimentation rate exceeds 50,000 cubic yards, the reservoir capacity has been reduced by at least 25%, or both. Bradbury, El Capitan, Hansen, Lake Hodges, Prado, San Vincente, Santa Felicia, Sutherland, and Twitchell Dams all impound an average of at least 250,000 cubic yards of sediment per year (Table 7.6). For these reservoirs, the rationale for intervention to restore sediment transport would be based upon the magnitude of the disruption to the natural system. Los Padres, Matilija, San Clemente, and Twitchell Dams have all lost at least 25% of their capacity as a result of sedimentation. For these reservoirs, one rationale for intervention, which might take the form of removal or sediment bypassing, would be the restoration of capacity.

This approach to prioritizing reservoirs does not consider the grain size distributions of impounded sediments. This information is especially important when delivery of sand to the coast is the rationale for intervention, because sediments larger or smaller than sand size are not usually suitable for beach nourishment. The example of Twitchell Dam is illustrative. This dam has a very high impoundment rate (exceeding 1,500,000 cubic yards per year), and the reservoir capacity has been reduced by about 27%. From this perspective, Twitchell would seem like an ideal candidate for providing sediments for direct or indirect beach nourishment. However, the vast majority of these sediments is smaller than sand size – typically in the clay particle range – and therefore are not suitable for nourishment. There is very little grain size distribution data available for most California reservoirs. However, Taylor (1981) has provided some broad guidelines for the basin-level estimation of sand content (discussed previously). If the resulting sand impoundment rate (versus sediment impoundment rate) or total sand impoundment is still large relative to a downstream coastal sediment-budget deficit, then intervention for sediment-related reasons may be justified. In some cases, the need to restore fish passages might lead to removal of fluvial impediments as well.

Matilija is the only dam in this set that is a reasonable candidate for removal, and such action is presently in the planning stage. The water supply and flood control functions of the other structures would probably override the importance of a demand for beach sand in considering removal of the dams, though structures might be removed to improve fish passage. There are other constraints on particular dams and reservoirs that might inhibit the manipulation of sediment deposits. The flood control basin created by Prado Dam, for example, contains habitat for endangered bird species (Least Bell's Vireo; Tracy, 2001). Excavation of sediment from this basin would be difficult because of the potential disturbance of the habitat. Similar constraints may apply to other of the reservoirs listed here as priority sites. However, more research on the environmental characteristics of the individual systems is required.

7.5.2 A Protocol for Debris Basin Identification

The average debris basin traps about 1,000 cubic yards of sand-size sediment per year. During years with extreme sedimentation caused by wild fire and/or intense precipitation, accumulation rates may be an order of magnitude larger. For larger basins, however, the accumulation rates may average more than 10,000 cubic yards of sand per year, with extreme events generating substantially larger volumes of sand. In order to preserve the protective function of debris basins, these accumulations of sediment must occasionally be removed. When debris basins are cleaned, the excavated material may be a resource with beach nourishment potential if the volume and quality are appropriate.

There are about 200 debris basins in California. Most of them accumulate relatively little debris in an average year. They are widely dispersed, and many are in remote locations. Further, debris removal does not occur on a regularly-scheduled basis. Instead, the basins are cleaned when circumstances warrant. This suggests the need for a flexible protocol for the identification of debris basins from which excavated sediments can be beneficially used. The protocol is two-pronged, and is to be implemented when debris basin cleanout is planned to maintain storage capacity and the sediment to be removed has a substantial sand content. Under these conditions, a debris basin may be targeted as a direct or indirect source of material for beach nourishment. It is assumed that the costs of debris removal and loading onto trucks will have already been met, and that provisions have been made for the transport and disposal of the material. For basins near the coast, the protocol directs that the material be transported to a designated beach nourishment site. For sites farther from the coast, the protocol uses volume and quality of sediment to determine whether sand substitution is feasible. Under this protocol, construction-grade sediment may be sold, and the resulting revenue used to purchase and deliver sand to the beach from more efficient locales.

7.6 Discussion

In California each year, more than 1,500,000 cubic yards of sand-size material are impounded behind dams and within debris basins. Much of this material could and should be transported to the coast via natural or anthropogenic means. We have identified twelve dams for which the volume of sand that might result from intervention is substantial, especially in the context of local sediment budgets (Table 7.7). If sand were bypassed around these dams at the same rate as long-term average sand deposition in the reservoir, then bypassing could offset 40% of the sediment deficit in these Southern California littoral cells caused by sand impounded by dams.

We have outlined a general protocol for the identification and timing of exploitation of sand resources trapped in debris basins. These protocols were, however, developed in the absence of key information concerning the practical aspects of their implementation. In the context of managing sediment supply to California beaches, the impacts of individual debris basins are small, and it would be difficult or inappropriate to develop blanket policies to govern their management. The data presented in this report indicate the highly variable nature of sediment production and accumulation in the debris basin system in Southern California. Further, they also imply that alteration of debris basin management practices as a means of improving sediment supply to the California coast is probably only a reasonable endeavor when directed at infrequent, large debris production years. This is especially the case when recalling that only about 50% of the sediment retained by debris basins is of a size suitable for Southern California beaches. Finally, it is commonly assumed that all sediment trapped within debris basins ultimately would have been transported to the coast. However, the works of Brown and Taylor (1982) and Barron (2001) indicate that much of this debris would have been deposited across the alluvial plain in long-term sediment storage, and perhaps less than 20% of the debris total might have been delivered to the ocean over short time scales.

Table 7.7 Benefits of Dredging and Bypassing Activities at Dams Designated as Potential Priority Sites for Sediment Supply Intervention

Littoral Cell	Average Annual Sand Deficit[1] (yd^3/yr)	Dam Name	Potential Sand Restoration[2] Dredging[3] (Maximum One-Time Benefit, yd^3)	Potential Sand Restoration[2] Bypassing[3] (Average Annual Benefit, yd^3/yr)	Percent of Sand Deficit Restored by Bypassing
Carmel River	45,558	Los Padres[5]	322,000	6,000	13
		San Clemente[5]	412,000	6,000	13
		Total	**734,000**	**12,000**	**26**
Santa Maria	624,671	Twitchell[5]	**14,194,000**	**346,000**	**55**
Santa Ynez	365,755	Bradbury[5]	**5,472,000,**	**116,000**	**32**
Santa Barbara	554,494	Matilija[5]	2,315,460	44,400	8
		Santa Felicia[5]	4,588,740	111,000	20
		Total	**6,904,200**	**155,400**	**28**
San Pedro	532,177	Hansen[6]	3,341,120	84,000	15
		Prado[6]	13,334,000	226,000	41
		Total	**16,675,120**	**310,000**	**56**
Oceanside	155,565	Lake Hodges[5]	2,132,000	26,000	17
		Sutherland[5]	92,000	2,000	1
		Total	**2,224,000**	**28,000**	**18**
Mission Bay	65,357	San Vicente[5]	456,000	8,000	12
		El Capitan[5]	2,112,000	32,000	49
		Total	**2,568,000**	**40,000**	**61**
TOTAL	**2,343,577**			**1,007,400**	**43**

[1] Data from Table 7.2
[2] Data are derived from volumes reported in Table 7.7 and Appendix A, assuming 20% sand
[3] Dredging assumes 100% recovery of sediment trapped in reservoir
[4] Assumes bypassing occurs at the same rate as long-term average sand deposition into reservoir
[5] Dam purpose is water supply
[6] Dam purpose is flood control

For the debris basins in Southern California, there are logistical obstacles to removing sediments and then reintroducing them into downstream fluvial or coastal systems. Some of these obstacles stem from environmental regulations that limit or prohibit the intentional deposition of sediments in active fluvial or coastal systems. Some obstacles stem from the difficulty and expense of removing and transporting sediment substantial distances to the coast. Other obstacles result from the temporal and spatial uncertainty in sediment production and impoundment.

It is clear that extreme sedimentation events, or the predicted occurrence of such events, will lead to the removal of sand-size material from debris basins. These events may create scenarios in which opportunistic beach nourishment is feasible. The requirement to dispose of sediments from debris basins for maintenance purposes already results in heavy vehicle traffic on foothill roads. Opportunistic beach nourishment requires only the funding necessary to transport sediments an additional distance to a pre-approved beach nourishment location.

It is recommended that policies be developed to facilitate the use of debris basin sediments for opportunistic beach nourishment. Such policies should encourage or require that sediments removed from debris basins, especially in response to extreme sedimentation events, be returned to the sediment transport system, preferably directly to the coast. Further, these policies should include anticipatory designation of nourishment sites, methods for beach nourishment (e.g., placing sand on a beach's berm, or grading onto the foreshore) and approved routes for heavy truck traffic. Alternatively, for excavation sites far from the coast, sediments could be sold for construction or fill purposes, and the revenues redirected to a regional beach nourishment account.

The development of such policies requires substantial additional research. More information is needed concerning the size distribution of sediments captured in some of the larger drainage basins and reservoirs. Sand content of sediments in some environments may be of insufficient volume to warrant aggressive approaches to sediment redistribution. Work is also needed to determine the location of a number of appropriate nourishment sites. Such determination may be based upon local erosion rates, wave energy climate (for the dispersal and reworking of nourishment sediments), or proximity to transportation arteries. Finally, at a larger planning scale, fundamental research into the influence of slope, precipitation, and fire on sediment production in watersheds is needed.

It is recommended that research be funded to describe environmental limits to sediment removal from individual reservoirs and debris basins. Research is needed on methods for separating the beach-compatible sand-size fraction from the rest of sediment impounded in reservoirs Finally, relatively little attention has been paid to how sediments can be delivered to the beach. Vehicular transport and the use of pipelines may be prohibitively expensive. Flushing materials downstream with natural or augmented flows may pose unanticipated environmental threats. Finally, it should be noted that most fluvial systems in California meet the ocean through an estuary. Any enhancement of sediment load in these streams will accelerate estuarine sedimentation, at least for time periods between large floods capable of flushing sediments to the sea. It is critical that research be conducted to understand and model potential effects so that undesirable negative impacts can be minimized.

7.7 REFERENCES

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7.8 Glossary

bankfull discharge- The elevation of the water surface of a stream flowing at channel capacity.

bedload- sediment that is transported by rolling or bouncing along a river bed.

channelized stream: A stream whose channel has been straightened and / or deepened to permit water to flow faster.

debris flow- a moving mass of rock fragments, soil and mud, much more than half of which are larger than sand size. Slow debris flows may move less than 3 feet per year; rapid ones reach 100 miles per hour.

drainage basin- the land area that contributes water to or drains to a river system or body of water. Synonym: watershed.

fluvial- of or pertaining to a river

littoral cell- A segment of coastline that includes sand sources, alongshore transport or littoral drift, and then a sink or sinks for the sand; also known as a beach compartment.

runoff- Flow of water over the land surface that occurs when precipitation rates exceed the infiltration rates of water into the soil or when precipitation falls on impermeable surfaces. Runoff may occur as **sheet flow,** in which water moves as a film over the ground surface, or as **channelized flow**, in which water is organized into distinct rills, gullies, streams, and rivers.

sediment flux- the volume of sediment discharged by a river per unit of time, typically measured in English units as tons per day or cubic yards per day. Synonym: sediment discharge.

sediment yield- the volume of sediment discharged per unit area per unit time from a watershed, typically measured in English units as tons per acre per day.

streamflow- the volume of water of flowing past a given point per unit of time, typically measure in English units as cubic feet per second. Synonym: water discharge.

suspended sediment- sediment that is fully entrained or suspended in the water column.

water discharge- the volume of water of flowing past a given point in a given amount of time, typically measured in English units as cubic feet per second.

water year- a water year runs from October of the previous calendar year to September of the current calendar year.

8. CONTRIBUTIONS FROM COASTAL CLIFF EROSION TO THE LITTORAL BUDGET

Coastal rivers, streams, and bluffs are the dominant sources of littoral material for California's beaches. As the construction of shoreline structures to protect eroding cliffs and bluffs has intensified in recent years, concern has developed regarding the significance of this armor in reducing the supply of sand to the beaches from the naturally eroding bluffs. In order to quantify this reduction, it is necessary to assess the extent of coastal bluffs and cliffs along the length of the coast of California, the significance of bluff erosion in producing beach sand, and the degree to which armor or other bluff protection has reduced this input. Littoral cell budgets determined to date suggest that in California, ~70-90% of the littoral sand is provided by rivers and streams (Bowen and Inman, 1966; California Coastal Commission, 1974; Best and Griggs, 1991a, b; Knur and Kim, 1999). Because the California coastline consists of a series of essentially self-contained littoral cells, however, it is necessary to evaluate the sand budgets of individual littoral cells to determine how important bluff erosion and, therefore, bluff armoring are to each cell.

8.1 The Geologic and Tectonic Setting of the California Coast

The geology of California and other states on the west coast of the United States is strikingly different from the geology found on east or Gulf coasts. Even a casual visitor to the coastline can observe the obvious differences between the coastal mountains and sea cliffs that characterize much of California's coastal zone and the broad, low-relief coastal plain, sand dunes and barrier islands of New Jersey or North Carolina. The Atlantic and Pacific coasts of North America have had very different geologic histories, and, as a result, are characterized by very different landforms that raise different issues for human occupancy.

California is on the leading edge of a large tectonic plate (the North American Plate) that has been colliding with the Pacific Plate to the west for millions of years. This collision and the subsequent plate interaction have produced California's unique and dynamic landscape. The diverse features such as the Sierra Nevada, the San Andreas fault and its associated earthquakes, the rugged coastal mountains of Mendocino and Big Sur, as well as the uplifted marine terraces and coastal cliffs that characterize much of California's coast all have their origins in millions of years of large scale tectonic processes that continue today.

Large-scale coastal landforms such as the coastal mountains, uplifted terraces, and sea cliffs also have been shaped by surface processes such as waves, rainfall and runoff, and landslides or other mass movements. In addition, sea level along the coast has changed constantly throughout geologic time in response to changing global climate and tectonic activity (Figure 8.1). As a result, the present position of the shoreline is only a temporary one. While the changes are not rapid, the evidence is clear that sea level has been rising for the past 18,000 years. Scientific consensus indicates that it will continue to rise in the foreseeable future, though the rate of rise and the maximum elevation that will be reached are uncertain. This should raise serious concerns about our increasingly intensive development of the shoreline, not just in California, but worldwide.

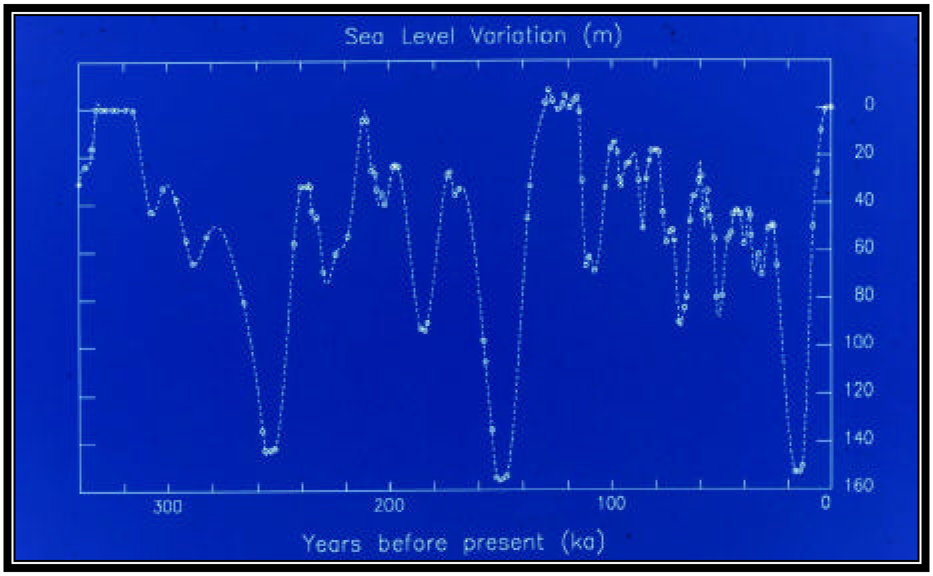


Figure 8.1 Sea level rise curve for the past 340,000 years (Lajoie, 1986)

Eighteen thousand years ago, the climate was considerably cooler than it is now and the earth was in the waning stages of a period of glaciation. Approximately 11 million cubic miles (45 million cubic kilometers) of seawater were locked up on the continents as ice caps and glaciers, which covered large areas of the earth. The removal of this seawater from the oceans led to a worldwide drop in sea level of about 430 feet (130 m). The shoreline along the coast of California at that time was five to fifteen miles offshore from its current position. As the climate warmed, the ice caps began to melt and the glaciers retreated. This melt water flowed into the ocean and sea level rose globally at an average rate of nearly 0.4 inches (1 cm) a year until about 5000 years ago. From about 5000 years ago until the present, the rate has slowed, although sea level has continued to rise at about .08 inches/year (2 mm/year) for the past century (National Research Council, 1987). There are convincing data and arguments that the present rate of sea level rise will continue and in all likelihood increase in the century ahead.

The rise in sea level that accompanied the period of global warming and ice melting that began 18,000 years ago flooded the continental shelves surrounding the continents. Along the coast of California, the shoreline progressed 5 to 15 miles (8 to 25 km) landward, with waves eroding and leveling the landscape and forming sea cliffs as the sea advanced. Throughout the period of major sea level rise (18,000 to 5,000 years ago), most of the coastline of California retreated at average rates of 2 to 6 feet (0.6 to 1.8 m) annually (based on the average width of the continental shelf and the time required for sea level to transgress the shelf). As sea level rise slowed, the erosion rate declined and began to approach the average rates of sea cliff retreat we witness today ranging from a few inches to 1 foot/year (30 cm/yr) in most places in the state (Griggs and Savoy, 1985).

8.2 Sea Cliffs and Sea Cliff Erosion

Results from this study show that the great majority (72%) of the coast of California consists of actively eroding sea cliffs. Earlier studies (USACOE, 1971) indicated that about 950 miles (1520 km), or 86%, of California's coast are eroding based on a large-scale regional analysis. Practically speaking, the entire coast of California has been retreating or eroding for the past 18,000 years. There is an important distinction, however, between the erosion or retreat of coastal cliffs or bluffs, which is an irreversible unidirectional process, and the seasonal or longer term erosion of the beaches, which can be recoverable. Thus, even as the coastline continues to retreat landward, beaches will be present as long as the supply of sand to the shoreline is maintained. When the shoreline of California was 10 miles (16 km) to the west, there were beaches on the outer edge of the continental shelf. As sea level rose and the shoreline moved eastward, the beaches migrated with the shoreline because sand continued to be provided by rivers, streams and cliff erosion. So, while the entire shoreline of California continues to slowly migrate landward and the cliffs and bluffs physically erode, the beaches migrate as well, but they are not necessarily eroding or narrowing. There are locations, however, particularly in Southern California, where the beaches are believed to be narrowing or eroding due to reduction of sand supplies; to date, however, this has not been comprehensively or quantitatively evaluated.

While the overall long-term statewide rate of coastal migration is a function of the rate of sea level rise, there are significant local or regional differences in erosion rates. These rates vary as a function of both the resistance to erosion of the materials making up the cliffs and the physical forces acting to wear away the cliffs (Benumof and Griggs, 1999; Benumof et. al., 2000). The hardness, or degree of consolidation of the cliff rock, and the presence of internal weaknesses such as joints or faults, all directly affect the resistance of the material to both slope failure and wave action. The wave energy reaching any particular stretch of cliffs, the presence or absence of a protective beach, the tidal range or sea level fluctuation, the climate, including rainfall, runoff, and the frequency of El Niño events or damaging storms, as well as groundwater flow, all influence the rate and scale of sea cliff retreat.

Sections of coast consisting of unweathered crystalline rock, such as the granite of the Monterey Peninsula, usually erode at imperceptibly slow rates, at least during the period of historic photographs. At some locations on the Monterey Peninsula, virtually no change was detected between photos taken over a 60 to 70 year span (Griggs and Savoy, 1985). Within these generally resistant areas, however, erosion rates can very considerably. Wave attack over time can cause the weaker zones, such as the fractures and joints, to form inlets and coves. The more resistant rock is left behind as points, headlands and sea stacks.

In striking contrast to the slow erosion of hard rocks, erosion can be far more rapid (over 1 foot (30 cm) per year, on average) where the bluffs consist of weaker sedimentary rocks such as shale, siltstone, sandstone, or unconsolidated materials such as dune sand or marine terrace deposits (Plate 81). In these areas, which are characteristic of much of Humboldt, Santa Barbara, Santa Cruz, and San Diego counties, the cliffs often retreat in a more linear fashion, producing relatively straight coastlines. Lithologic, stratigraphic and structural weaknesses or differences are the key factors affecting erosion rates in sedimentary rocks. Cliff erosion is due not only to waves undercutting the base of the cliff, but also to rockfalls, landsliding and slumping higher on the cliff face, often as a result of weakening due to groundwater percolation. The orientation and spacing of joints in the sandstones, siltstones, and mudstones that make up the cliffs surrounding northern Monterey Bay are the dominant factors affecting cliff retreat in this area (Griggs and Johnson, 1979).

Plate 8.1 Erodible bluffs consisting of unconsolidated marine terrace deposits and soil in San Mateo County.

Cliff failure during strong seismic shaking represents a significant but little appreciated coastal hazard, primarily due to the infrequent nature of large earthquakes. The potential for earthquakes that can affect coastal bluffs is high along the entire length of the state's coastline (Plate 8.2; Griggs and Scholar, 1997). No part of the coastline of California is more than 15 miles (24 km) from an active fault (Jennings, 1975), and many areas are considerably closer.

Plate 8.2 Seismically-induced bluff failure in Daly City, 1989

8.2.1 Erosion Rates

It is important to understand exactly what is meant by *average annual erosion rate.* Geologists normally measure the amount of coastal retreat or erosion over the time interval spanned by available aerial photographs or historic maps, and divide this distance by the number of years of record to get an average annual rate. However, years of observation, particularly during severe winters such as the El Niño years of 1982-83 and 1997-98, have shown that erosion in California is usually episodic and irregular. Although the "average" rate of erosion along a particular stretch of sea cliffs may be determined as one foot/year (30 cm/year), erosion may occur as large five to ten foot wide blocks failing instantaneously every 10 to 15 years (Plate 8.3), rather than in even, one foot annual increments. Now that we have a better understanding of longer-term climatic periods and the impact of El Niño events on the coastline, short-term records and erosion data (i.e. less than 25 or 30 years) should be used with caution, as they may not represent long-term patterns.

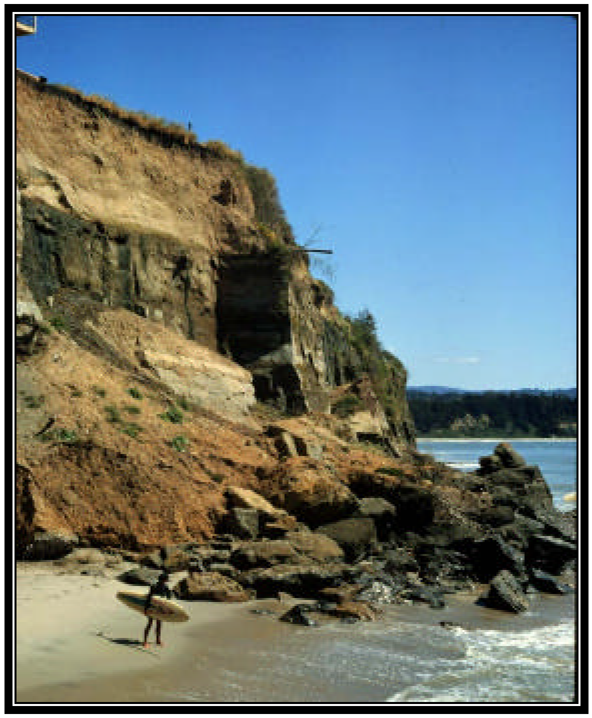


Plate 8.3 Episodic coastal bluff failure in Capitola.

8.2.2 The Eroding Coast of California: Historical Perceptions

A 1971 Corps of Engineers regional inventory of the California coastline classified only 14.2% of the coast as *non-eroding* while 7% (76.4 miles, or 123 km) were classified as *critical erosion* (defined as areas where structures and/or utilities were threatened), with the remainder designated as *non-critical erosion* (U.S. Army Corps of Engineers, 1971). A subsequent investigation by the California Department of Navigation and Ocean Development (Habel and Armstrong, 1977) defined the erosion problem somewhat differently. Approximately 99.4 miles (160 km, or 9%) of the coast were delineated as eroding with existing development threatened, and an additional 480 miles (772.5 km; 27.3%) were classified as eroding at a rate fast enough that future development would eventually be threatened. Thus, a total of 335.5 miles (540 km; 36.3%) of the California coastline were considered threatened due to high erosion rates.

The most recent inventory of hazardous coastal environments expands the scale of the problem areas further. In 1985, sixteen coastal geologists participated in the preparation of a statewide inventory of coastline conditions, classifying 310.7 miles (500 km; 28.6%) as *high risk*, and an additional 405 miles (650km; 36.8%) as requiring *caution* (Griggs and Savoy, 1985). These data indicate that two-thirds of the California coastline is subject to a significant coastal erosion hazard.

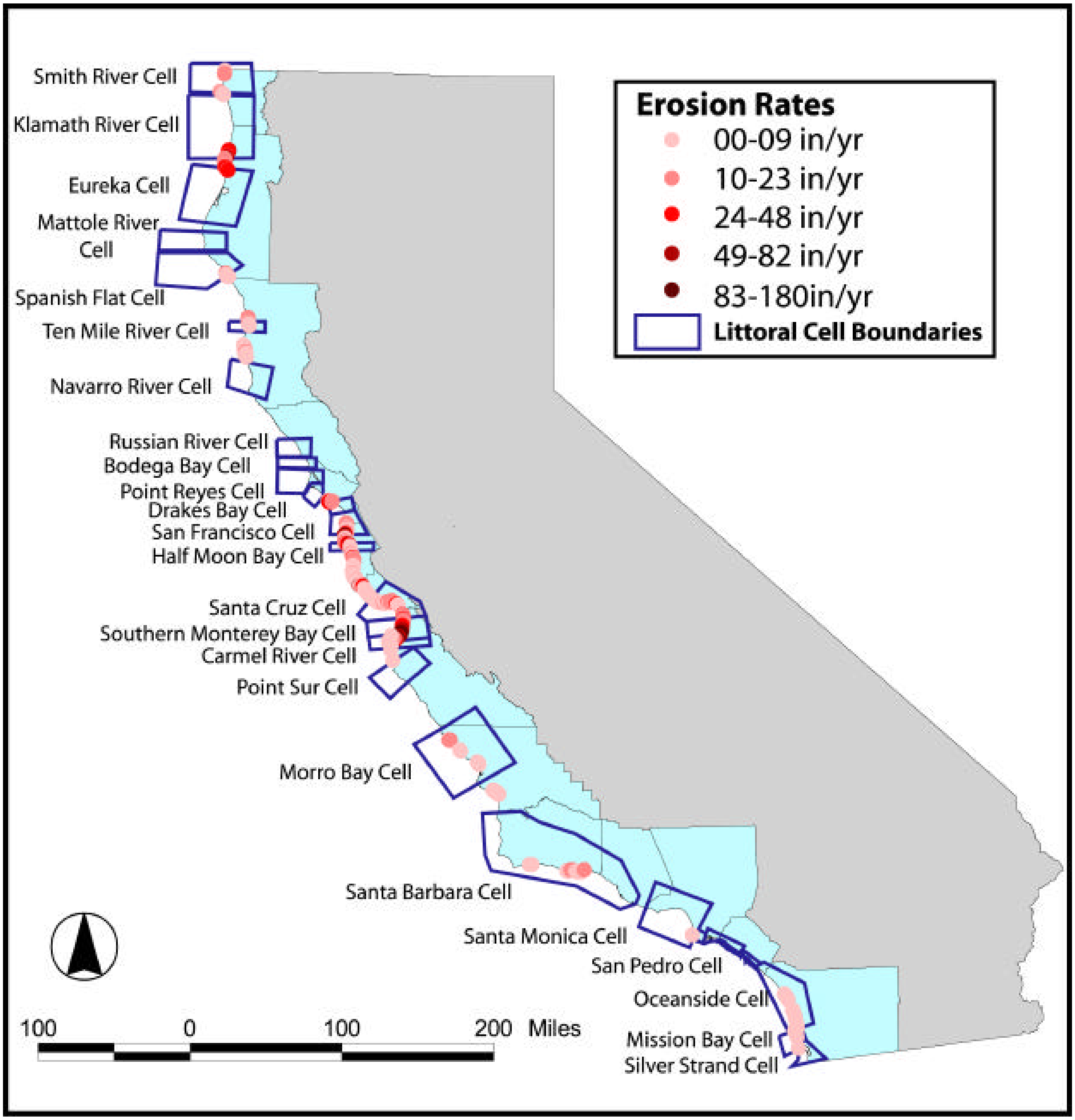


Figure 8.2 Documented erosion rates and littoral cell boundaries for California

(Habel and Armstrong 1977)

8.3 A Statewide Inventory of Sea Cliffs and Their Potential Sediment Contributions to the Littoral System

A statewide assessment of the distribution of sea cliffs, their general lithology or rock type, and their general resistance to erosion was undertaken as part of this study in order to develop a semi-quantitative sense of the potential for sand contribution from the cliffs to California's littoral system. A complete quantitative assessment of statewide sand contribution from the cliffs, however, is beyond the scope of this investigation. While the determination of cliff height and alongshore length of individual sea cliff segments is relatively straightforward, the measurement of long-term cliff erosion rates and the calculation of the percentage of littoral-sized material and its geographic distribution by rock types along the 1100 miles (1760 km) of California coast will be a major undertaking.

8.3.1 Distribution of Cliffs

The coast of California can be broken down into three very general categories: 1) high relief, steep cliffs (Plate 8.4); 2) bluffs eroded into lower relief (less than 300 ft [100 m] in height) marine terraces (Plate 8.5); and 3) coastal lowlands or plains (Plate 8.6). The first two categories may be combined and generally called cliffs. The high relief, steep cliffs of California are composed predominantly of resistant volcanic or granitic rocks and are generally not a major contributor of sand sized material to the littoral budget. The Franciscan Formation (see glossary for definition) is a complex assemblage of different rock types; some that are very resistant to erosion and form promontories or sea stacks, and others that are very weak.

Plate 8.4 Steep, high-relief cliffs south of San Francisco

The lower-relief marine terraces, however, play a more important role in terms of sand contribution. Marine terraces are primarily comprised of Tertiary marine sedimentary rocks, capped by Quaternary terrace deposits which, when eroded, will produce a greater percent of sand sized material than the high relief, steeply cliffed shoreline. After reviewing the *Assessment and Atlas of Shoreline Erosion Along the California Coast* (Habel and Armstrong, 1977), we determined that 72% if the California coastline can generally be designated as sea cliffs. More specifically, 13% of the coastline is high relief, steep cliffs or mountains, and 59% of the coastline is low relief (less than 300 ft [100 m]) wave-cut bluffs or terraces. The high relief, steep cliffs are found predominantly in Northern California from Del Norte County to Mendocino County and along the Big Sur coast of Monterey and San Luis Obispo Counties. High relief, steeply-cliffed outcrops and headlands can be found along several areas of the Southern California coastline as well; Pt. Loma and the Santa Monica Mountains are two examples.

Plate 8.5 Low-relief, uplifted marine terraces in Santa Cruz County.

Plate 8.6 Coastal lowlands, Orange County.

8.3.2 Distribution of Rock Types

The general geology of the entire California coast was mapped from the California Division of Mines and Geology (CDMG) 1:250,000 scale geologic maps using a Geographic Information System (GIS). While rock types have now been delineated and are accessible in a GIS system for the entire coast, the assessment of the grain size distribution of individual rock units, and therefore their potential sand contributions to the littoral system, is hindered by the nomenclature used on the CDMG maps. For example, CDMG designated rock units as marine, non-marine, volcanic, *et cetera*, which doesn't provide any grain size information. Similar rock units were combined, however, to get an overall sense of their importance along the 72% of the state's shoreline that is backed by sea cliffs.

The most extensive cliff exposures are those aggregated as *Pliocene Marine*, which constitute over a third (39%; 428 miles or 688 km) of the entire 1100 miles (1760 km) of coastline. These are Pliocene-age (2-13 million years old) sedimentary rocks, such as mudstones, siltstones, or sandstones of marine origin. While Pliocene-age sedimentary rocks in general are relatively weak and erodible, there is no way to determine from the CDMG maps whether these sedimentary rocks are sandstones that would contribute sand as they erode, or fine-grained shales, mudstones, and siltstones that do not contribute sand-sized material.

Unconsolidated Quaternary sediments, such as dune sands, marine or non-marine terrace deposits (terrace deposits are sediments that were deposited on a wave-cut platform or terrace when sea level subsided; they may be beach, dune or stream deposits but are usually very sandy), all relatively coarse-grained and potentially-important beach sand sources, constitute the second largest exposures at 28% or just over 300 miles (480 km) of coastline. These materials are usually poorly consolidated and therefore prone to erosion. As a group, based on their erosion patterns and grain size, these sediments are probably the most significant in terms of contribution to the beach sand budget of all coastal cliff materials.

Rock types combined as *Miocene Marine, Oligocene Marine, Tertiary Marine* and *Cretaceous Marine* make up a combined 19% (335 miles or 540 km) of the state's coastline. Again, there is no way, without detailed additional research on the original references on which the map classifications were based, to discern whether or not these are sand-rich sediments, such as sandstones, or finer-grained rocks, such as shales, mudstones or siltstones.

The assessment of the distribution of rock types is complicated by the fact that the majority of the coast of California consists of uplifted marine terraces, in which underlying sedimentary bedrock is capped by unconsolidated terrace deposits. As the cliffs erode, both the underlying bedrock and the overlying terrace deposits collapse onto the beach, each contributing a different percentage of littoral-sized material to the sediment budget of the particular cell (Plate 8.7).

Detailed topographic and geologic mapping of the bluffs, which requires ground surveys and sampling, is necessary in order to make accurate determinations of the importance of the erosion of specific sections of the cliffs to the littoral budget.

In aggregate, sedimentary rocks and poorly consolidated sediments constitute 939 miles (1502 km) or 85% of the entire 1100-mile coastline of California. Interestingly, the earlier statewide assessment published by the Corps of Engineers in 1971 reported that 86% of the state's coastline was eroding.

Plate 8.7 Eroding coastal bluffs exposing mudstone bedrock at beach level and overlying sandy terrace deposits

The other major units exposed along the shoreline are the *Franciscan Formation* (a complex of older metamorphic and sedimentary rocks that comprises 10% of the coastline), *granitic rocks* (3%), and *Tertiary and Miocene Volcanics* (<1%). In general, these rocks tend to be much harder and more resistant to erosion than sedimentary rocks, and it is often these rock types that form the resistant headlands or points along the state's shoreline. For example, along the Northern California coast, Pt. St. George, Trinidad Head, and Pt. Delgada are all Franciscan Formation outcrops. Bodega Head, Pt. Reyes, Montara Point, Pt. Pinos and Pt. Cypress are all granitic. Proceeding to the south central coast, Pt. Sur, Pt. San Martin, Piedras Blancas and Pt. San Luis are all Franciscan Formation. These are very resistant rock types, most of which are very fine-grained, erode very slowly and, in the case of the Franciscan Formation and volcanic rocks, are not significant sources of sand for the beach.

8.4 Quantifying Sand Contributions to the Shoreline From Cliff and Bluff Erosion

California's beach sand dominantly comes from rivers and streams and, to a lesser extent, from erosion of the coastal bluffs and cliffs. Although no comprehensive quantitative analysis of sediment sources has been completed for the state's coastline, the regional littoral budgets that have been developed to date, with the exception of the budget for the Oceanside cell, indicate that rivers and streams provide ~ 70-90% of the littoral sand (Bowen and Inman, 1966; California Coastal Commission, 1974; Best and Griggs, 1991a, b; Knur and Kim, 1999; Flick, 1994).

The movement of sand along the California coastline can be understood best in terms of littoral cells or beach compartments (Inman and Frautschy, 1966). A littoral cell can be defined as a segment of coastline that includes sand sources, alongshore transport or littoral drift, and then a sink or sinks for the sand. The most important sand sources for California's littoral cells are the state's rivers, streams and coastal cliffs and bluffs. The major sinks are the many submarine canyons that cross the continental shelf and enter shallow water and the extensive areas of sand dunes. In some areas, southern Monterey Bay for example, sand mining was also a major loss or sink for many years. Many of California's littoral cells have been altered significantly by human activity, which has reduced the availability of sand at the shoreline. The evaluation and quantification of human impacts on sand supply to the various littoral cells along California's shoreline is the core of this study.

8.4.1 Quantifying Cliff Contributions

The annual production of littoral sand from a segment of shoreline through sea cliff erosion (Qs) is the product of the cross-sectional area of sea cliff (Area = alongshore cliff length times cliff height), the average annual rate of cliff retreat (feet/year), and the percentage of the material that is sand-size (Figure 8.3).

The geology of the sea cliffs varies widely alongshore and, therefore, all of these parameters vary from location to location. As mentioned in Section 8.3.2, where the coastal cliffs consist of uplifted marine terraces, there is typically an underlying and more resistant bedrock unit, which may or may not contain appreciable quantities of sand, and also an overlying sequence of sandy marine terrace deposits. Each of these units must be analyzed for its individual sediment input. In order to make qualitative assessments or quantitative measurements of the contribution of coastal cliff retreat to the littoral system, it is necessary to divide the coast into manageable segments that are somewhat uniform. These divisions are based on similarities in morphology and rock type along specific segments of coastline. The estimates of sand contributions from the individual segments can then be added to arrive at a total contribution to the beach for a larger area, such as a specific littoral cell (Best and Griggs, 1991a, b).

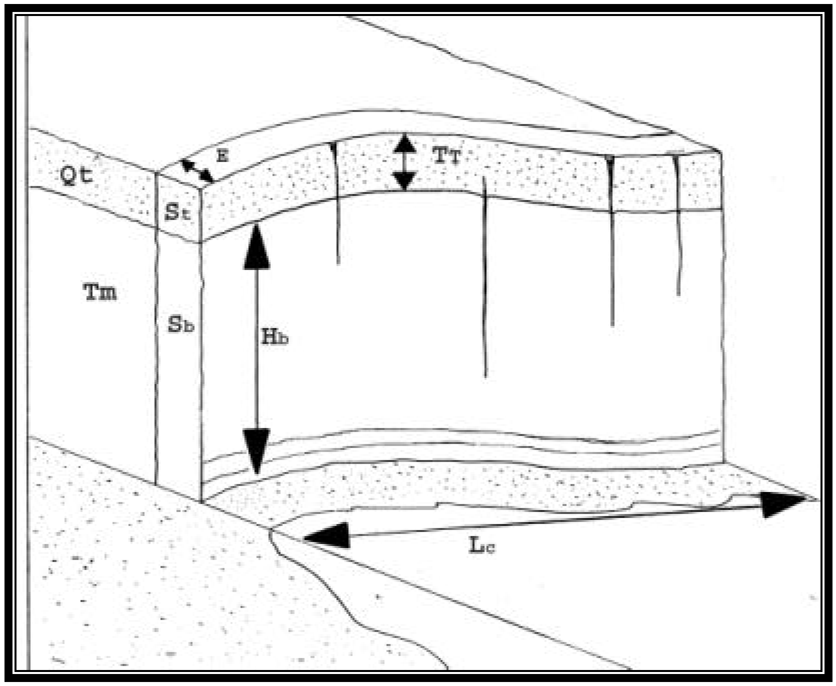


Figure 8.3 Coastal bluff showing components involved in determination of sand contribution
(St: % sand content of terrace deposit, Sb: % sand content of bedrock, Hb: height of bedrock(ft), Tt: terrace thickness (ft), Lc: length of cliff (ft), E: Erosion rate (ft/yr), Qt: terrace deposit, Tm: Bedrock)

8.4.2 Area of Eroding Sea Cliffs

The area of eroding sea cliff that potentially provides sediment to the littoral budget can be determined from measurements of cliff length and height. Cliff height can either be measured directly in the field or taken from accurate topographic maps. USGS topographic map sheets provide for semi-quantitative estimates of cliff height, although the exact height is not included on these maps except at the locations of specific benchmarks. Where uplifted marine terraces form the coastal cliffs, which is the case for large areas of the California coast, the cliff height is often relatively uniform alongshore for considerable distances and an average height can be used. Where marine terraces form the sea cliff, there are typically two distinct geologic units that are exposed and that contribute to the sand budget: the underlying bedrock, which may vary widely in composition, and the overlying marine terrace deposits, which normally consist of relict beach sand (Plate 8.7) and coarser marine and occasionally non-marine deposits . The thickness of the different units exposed in the sea cliff can be determined from either direct field measurements, near-horizontal aerial photographs taken at cliff-top altitude from offshore, or through detailed photogrammetric analysis of stereo aerial photographs.

8.4.3 Grain Size of Cliff Materials

A grain size analysis of representative samples of cliff material is necessary in order to quantify the percentage of sand in the cliffs. Samples analyzed in this study include beach sands, unconsolidated marine terrace deposits, and consolidated sedimentary rocks, which were disaggregated or broken down in order to determine their grain sizes. Cliff samples were selected for collection based on how representative they were of individual coastal segments and on access to the representative cliff sites.

Measuring the amount of sand-sized material in a disaggregated sediment sample is straightforward and can be accomplished by shaking the sample through a set of screens or sieves and weighing the amount that remains on a sieve of a given size opening. Where the rock is a highly consolidated or well-cemented shale, mudstone or siltstone, however, disaggregation is very difficult and failure to break the rock down to its constituent particles (as would happen naturally in the surf zone) will yield a sand size percentage that is inaccurate and too high. The importance of bluff erosion to the sand component of the littoral budget would then be overestimated.

In order to accurately determine the amount of sand-size material in the consolidated rock samples from the cliffs, we first physically broke them down to smaller (one or two cm in diameter) fragments. Fifty to 100 grams of the cliff material were then put into a rock tumbler with an equal amount of beach sand from the site (for use as an abrasive) and water. After 12-24 hours of tumbling, the sample was dried and sieved to determine the weight of littoral material remaining after subtracting the weight of the added beach sand. With many samples, this was adequate to completely disaggregate or abrade the bedrock sample so the amount of littoral sized material derived from the rock could be determined. If any larger fragments (coarser than 1 mm) still remained, which was the case for some of the more resistant cliff materials, then they were visually analyzed to determine if they were shale or mudstone fragments that would not contribute to the littoral budget; this material was discounted. This approach provided an accurate measurement of the actual percentage of resistant littoral-size material present in each bluff sample (Appendix B). These percentages were then used in the calculations of the littoral sand contributed from each particular segment of bluff sampled and analyzed.

While it is common practice to refer to most beach sediment as “sand,” grain sizes found on beaches in California range from very fine sand to cobbles. Sand is defined as all particles between 0.062 mm and 2 mm in diameter; this grain size is characteristic of most California beaches. Very fine-grained sand, ranging from 0.062 to 0.125 mm in diameter, doesn’t usually remain on most California beaches due to the high-energy wave environment. Hicks (1985), in an investigation of littoral transport processes and beach sand in northern Monterey Bay, discovered that there was a "littoral cut-off diameter", or a grain size diameter, characteristic of particular segments of coast, that serves as a functional grain size boundary in that very little material finer-grained than this diameter is found in the beach. The littoral cut-off diameter is primarily a function of wave energy along any particular beach or stretch of coast. Studies along the coast of northern Santa Cruz County (Hicks, 1985; Best and Griggs, 1991a, b), which is a relatively high-energy exposed coast, indicate a littoral cut-off diameter of ~0.18 mm. Analysis of beach sand samples collected throughout the Santa Barbara cell in this study indicate an approximate littoral cut-off diameter of 0.125 mm, whereas in the Oceanside cell, the cut-off diameter is finer-grained (0.0875 mm). In most beach samples analyzed, ~95-98% of the sand in the beaches of these cells was coarser-grained than this cut-off diameter. It is important to realize that 0.062mm, the smaller value used to define "sand" on the Wentworth scale, is simply one grain-size designation that was somewhat arbitrarily defined as the dividing line between silt and sand; it carries no specific hydraulic distinction. Previous studies (e.g. Bowen and Inman, 1963; Diener, 2000) that assumed all sediment coarser than 0.062 mm is suitable beach sand for a particular site have probably overestimated the local cliff contribution.

8.4.4 Cliff Erosion Rates

Another factor in determining the amount of sand contributed by cliff erosion to a littoral cell is the average rate of sea cliff retreat. Episodic and locally-variable rates of cliff retreat result from a combination of 1) alongshore differences in the strength of cliff materials (Griggs and Johnson, 1979; Benumof and Griggs, 1999), 2) the infrequent coincidence of high tides and extreme storm waves capable of causing significant erosion and removing debris from the base of the cliff, 3) concentration of wave energy due to local bathymetry (Benumof et al., 2000), and 4) the presence or absence of a protective beach. Rates of bluff retreat also may be influenced by large earthquakes, such as the 7.1 magnitude October 17, 1989 Loma Prieta Earthquake. This was the largest earthquake to affect the Central coast since the 1906 San Francisco earthquake, and it produced isolated cliff failures from Marin to Monterey counties (Plate 8.2; Plant and Griggs, 1990).

Where either qualitative or quantitative analyses have been completed (Griggs and Johnson, 1979; Benumof and Griggs, 1999), it is evident that the lithology and structural weaknesses of the cliff-forming materials exert the dominant control on rates of seacliff retreat.

Rates of sea cliff erosion can be computed from a comparison of time-sequential aerial photographs, ground photographs or historic coastal surveys and maps. Typically, the position of the sea cliff edge at specific locations or transects is identified on individual maps or aerial photographs over the longest time span for which data are available and is used to determine long-term average annual cliff erosion rates. There are a number of techniques with varying degrees of accuracy for making these measurements; the more precise measurements are the most time consuming and hardware/software intensive (Moore, 2000).

Because of the time involved and the equipment and aerial photographic or map database needed to accurately measure long-term sea cliff erosion rates, there have been few attempts to calculate bluff retreat rates in California. *Living with the California Coast* (Griggs and Savoy, 1985) included input on a regional basis from a group of coastal geologists in California, and maps included in that volume incorporate the site-specific cliff erosion rates known at that time. More recently, the city of Pismo Beach, California completed a bluff erosion study in which bluff retreat rates were estimated by analyzing aerial photographs dating back to 1954, topographic maps, and recent field measurements (Earth Systems Consultants Northern California, 1992). Moore, Benumof and Griggs (1998) completed coastal erosion studies for San Diego and most of Santa Cruz County in which bluff retreat rates were calculated using photogrammetric analysis. Diener (2000) calculated cliff retreat rates from Point Conception to Santa Barbara by comparing United States Geological Survey (USGS) 7.5' topographic maps produced in 1947 and a set of 1:25,000 scale aerial photographs taken in 1997.

In a statewide coastal hazards study (Griggs, Pepper and Jordan, 1992), it was determined from interviews with local government planning staff that the most frequently cited data need was that of shoreline and bluff erosion rates. Nearly half of the respondents indicated a need for such information. Yet, we have found through the present study that there are still very few additional published or easily accessible cliff erosion rates beyond those previously published by Moore et al. in 1998 for Santa Cruz and San Diego counties. There have been a number of site-specific studies for individual parcels where cliff erosion rates were required as a condition for development permits, but there has been no attempt to consolidate these for broader application.

8.5 Statewide Armoring and the Reduction of Beach Sand Supply From Coastal Bluffs

We have shown that eroding bluffs and cliffs make up about 950 miles (1520 km; 72%) of the coast of California. Specifically, 13% of the coast consists of more resistant, high relief, steep cliffs or mountains, and 59% of the shoreline is low relief (less than 300 ft [100 m] high) wave-cut bluffs or terraces. The low bluffs typically consist of a sedimentary rock basal section overlain by sandy, unconsolidated terrace deposits. These bluffs often are cut into nearly flat, uplifted marine terraces and are intensely developed (Plate 8.8). Because the sedimentary rocks and the overlying terrace deposits are relatively weak and highly susceptible to both marine and subaerial erosion, and because they have been intensely developed, many of these areas now have been armored to protect existing development. Halting coastal bluff erosion has reduced the amount of sand contributed by the eroding bluffs to the littoral budget.

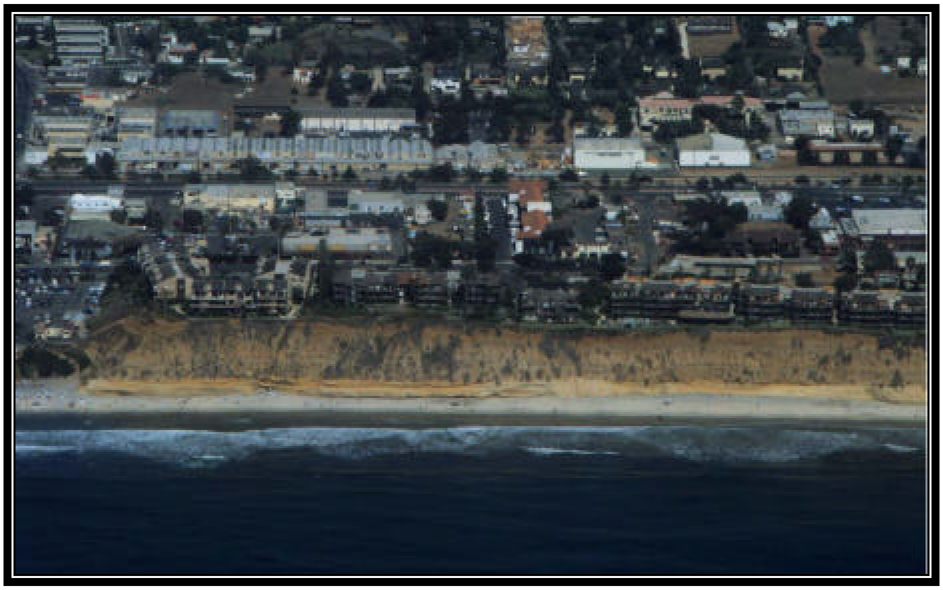


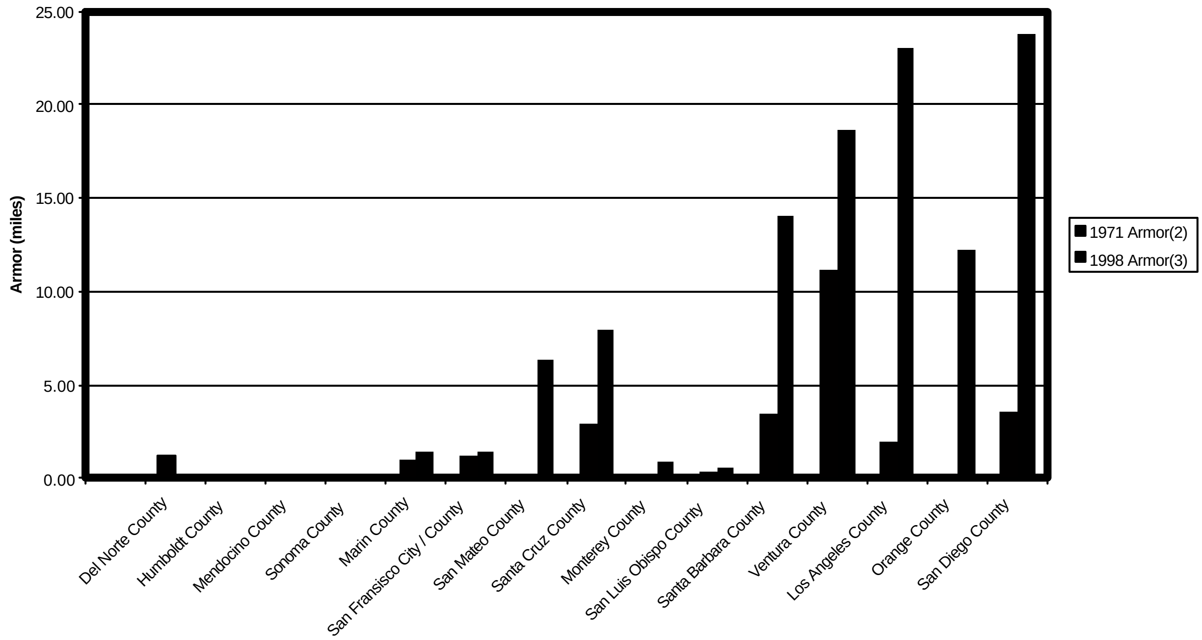
Plate 8.8 Developed terrace and bluffs at Solana Beach, San Diego County

All research and studies to date, with the possible exception of those focused on the Oceanside littoral cell, indicate that the volume of beach sand contributed by bluff erosion along the shoreline of California is substantially less than the volume contributed to littoral cells from rivers and streams. However, as fluvial contributions have decreased, bluff contributions have become more important in local sediment budgets. Thus, coastal armor, which prevents bluff sediment contributions from reaching the beach, could have a significant impact on the sediment budget in individual littoral cells. As the development of the Southern and Central California coast has expanded, and as coastal storm damage has intensified since 1978, the extent of coastline protected by armor has continued to increase.

8.5.1 Previous Inventories of Coastal Armor

In the 1971 U. S. Army Corps of Engineers statewide shoreline inventory, 26.5 miles (42.7 km) of California coastline (2.5%) were listed as protected by some sort of armor (exclusive of breakwaters and groins; Table 8.1). Six years later, in 1977, the California Department of Navigation and Ocean Development, now the Department of Boating and Waterways, determined that 62 miles (~ 100 km) or 5.7% of the state's coastline had been protected by shore-parallel engineering structures, and an additional 18.8 miles (30.2 km; 1.7%) were protected by breakwaters, for a total of 81 miles (130.2 km) or 7.4% of the coast. The most recent inventory of armoring in the San Diego region, *Shoreline Erosion Assessment and Atlas of the San Diego Region*, was done by the Department of Boating and Waterways in conjunction with the San Diego Association of Governments (Flick, 1994). This atlas provided armor location maps for the San Diego region, but did not include a summary of the total linear miles of armor.

Table 8.1 Comparison of Length of Armor by County in 1971 versus 1998



(2) From 1971 National Shoreline Study California Regional Inventory, US Army Corp of Engineers
(3) From 1998 Aerial Oblique Digital Photography Transferred to GIS

There are significant challenges to accurately quantifying the amount of coastline that has been armored. This section points out and explains some of the data discrepancies discovered in this investigation. It is not clear how the armor data that were included in either the 1971 USACOE or the 1977 state study were obtained.

In *Living with the California Coast* (Griggs and Savoy, 1985), a group of coastal geologists analyzed coastal hazards mile by mile along the state's coastline. Their maps indicate that approximately 85 miles (136 km), 7.7% of the coast, were armored by seawalls or revetments, and another 20 miles (32 km) were protected by breakwaters, for a total of 105 miles (168 km) of armor by 1985 (9.5% of the entire 1100 miles (1760 km) of coastline). For that study, the individual geologists who knew the specific sections of shoreline mapped the distribution of armor, so this was probably an accurate assessment of the extent of armored areas at that time.

In a subsequent study analyzing the state's coastal hazard policies and practices, using first-hand interviews with local government planners, Griggs, Pepper and Jordan (1992) reported that a total of 130 miles (208 km) or 11.8% of the coast were now protected by some form of hard structure. The study looked at the extent of armor by city and county. As might be expected, the heavily populated and developed central and southern portions of the state's coast had been protected to a far greater degree than the less-populated northern coast. For example, seventy-seven percent of the 17-mile (27 km) coastline between Carpinteria and Ventura and 86% of the

8-mile coastline from Oceanside to Carlsbad had been protected. In comparison, only 8% of the 45 miles (73 km) of Del Norte County had been protected at the time of the study.

The California Coastal Commission, as part of their Regional Cumulative Assessment Project (ReCAP), reviewed coastal armoring practices in the Monterey Bay Region (Plate 8.9) as well as the Santa Monica Mountains/Malibu area. For the Monterey Bay Region, from the San Mateo/Santa Cruz county line south through Point Lobos in Monterey County, aerial photographs from 1978, 1986, and 1991 were compared to determine changes in armoring. In 1978, there were approximately 9.6 miles (6 miles in Santa Cruz County and 3.6 miles in the ReCAP portion of Monterey County) of armoring in this area. This number increased to 11.9 miles (8.2 miles of armoring in Santa Cruz County and 3.7 miles in the ReCAP portion of Monterey County) of armoring in 1986. By 1993, there was only a slight increase in the armoring of Santa Cruz County, bringing the total to 12 miles (8.2 miles of armoring in Santa Cruz County and 3.7 miles in the ReCAP portion of Monterey County) of armoring for this study area. These numbers do not include protection by means of breakwaters, jetties or groins; they also do not include the addition of rock to existing walls for maintenance purposes (California Coastal Commission, 1995).

Plate 8.9 Rip-rap armoring the bluffs at the mouth of Corcoran Lagoon, Santa Cruz County

The study site for the Santa Monica Mountains/Malibu ReCAP study extends from Point Mugu in Ventura County to Topanga Canyon in Los Angeles County. Using aerial photographs from 1978 along with an analysis of Commission permit actions, ReCAP found that approximately 11.4 miles or 35% of the study area were protected by seawalls, rip-rap, or retaining walls. From 1978 to 1996, the California Coastal Commission authorized shoreline protective structures along approximately 2.8 miles of shoreline in this study area. Thus, the total amount of shoreline protective armoring (including approximately 0.6 miles of armoring that is not permitted) at the time of the ReCAP study for the Santa Monica Mountains/Malibu area was 14.8 miles (California Coastal Commission, 1998).

8.5.2 Current Inventory of Coastal Armor

To update the extent of coastal armor along the coast of California, a database of coastal structures was created in a GIS. This was accomplished using a combination of oblique video, and photographic coverage of the coast obtained during the past several years. The more developed portions of the state's coast are the areas where both urbanization and seawall construction are the most extensive and also where the photographic coverage is the most complete and up-to-date.

We also contacted planners in individual cities and counties to determine what their permit records showed for the amount of armor that had been permitted in their individual municipality. Several important findings came out if these inquiries. For the most part, few local governments either compile or track the amount of armor that has been built. In most cases, there was either no response or the staff planner was not able to provide the information and didn't know who could. In one case, we were able to contact the same staff person we contacted in the 1992 study and were given a value for the amount of armor that turned out to be less than the value provided nine years earlier. We then discovered that in the 1992 interviews some local government staff provided data on not only shore-parallel coastal seawalls or rip-rap, but also armoring along channelized river mouths and within harbors to protect shorelines. This provided a strong rationale for developing accurate recent values for the extent of coastal armor.

Video coverage of the area from San Diego to Santa Barbara flown in 1998 was utilized, as was 2001 digital and video photography of the area from San Francisco to Santa Cruz. Hard armor structures were visually interpreted from the video coverage and mapped in a GIS format. The armoring of the remaining north and central coast areas not covered by the digital video were delineated using a combination of *Living with the California Coast* (Griggs and Savoy, 1985) and, where we could obtain data, from the local government planning or public works departments. Recent photo coverage was not available for most of the coast north of San Francisco. This is an area, however, where overall coastal development and consequently coastal protection is of relatively limited extent.

Even with low-flying aircraft and high-resolution oblique digital photography or digital video, in some cases it was difficult to identify low seawalls and rip-rap where they were low relief, partially covered with sand or vegetation, or otherwise obscured. Thus, the values we have determined for the length of armoring along the coast are minima, as there may be structures that simply are not visible from the air. There is no efficient way to accurately document the extent of armor without physically walking the protected areas.

Plate 8.10 Rip-rap armoring coastal bluffs in Santa Cruz

Plate 8.11 A curved-face concrete seawall under construction in Monterey Bay

The armor was divided into 2 categories: rip-rap/revetment (Plate 8.10) and concrete, timber and sheet-pile seawall (Plate 8.11). Approximately 102 miles (165 km; 9%) of the state's coastline are presently armored; 58 miles (93 km; 57%) of this armor protect coastal lowlands or dunes while the remaining 44 miles (72 km; 43%) of the armor protect sea cliffs. Of the total armor, 41% is concrete, timber and sheet-pile seawalls, and 59% is rip-rap/revetment or a combination thereof.

The total percentage of the coast verified as armored in this investigation (9% or 102 miles (165 km)) is less than that reported in the last inventory (11.8% or 129 miles (208 km); Griggs, Pepper and Jordan, 1992). As discussed above, we believe that this is due to some local government planners having reported the length of rip-rap or other structures that were protecting interior margins of marinas and flood or bank control projects along river mouths in their estimates of total armoring in their region. Another source of error may be the inability in some cases to recognize low relief structures or those that have been designed to match the existing bedrock (Plate 8.12) from oblique low altitude aerial photography.

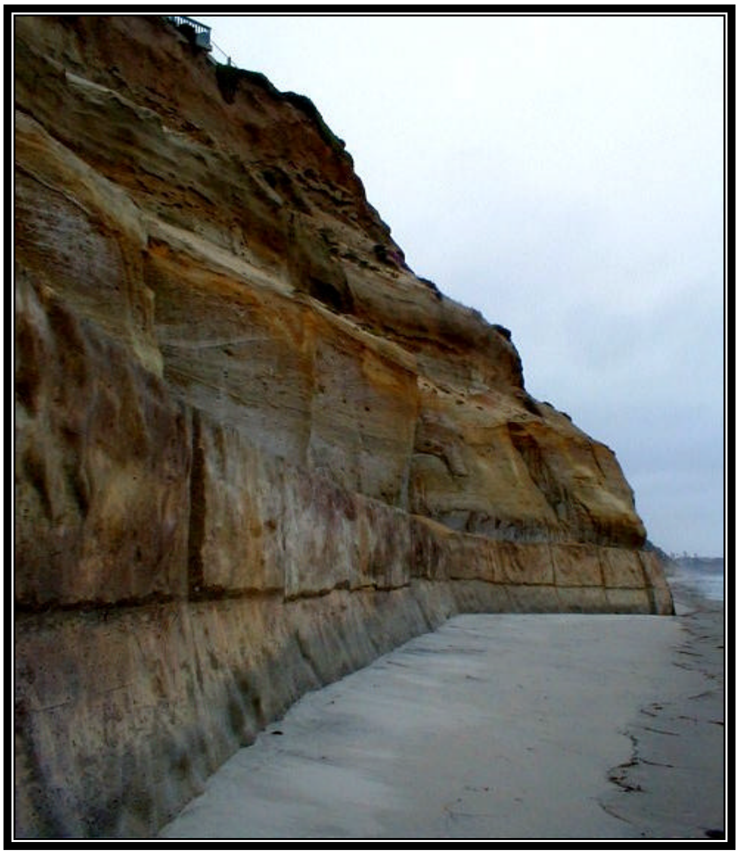


Plate 8.12 A seawall in Encinitas designed to protect the base of the bluff and visually blend with existing bedrock

8.6 The Oceanside and Santa Barbara Littoral Cells: Contribution of Sand From Sea Cliff Erosion and Impacts of Coastal Armoring

To assess the direct impact of coastal armor on the contribution of littoral sediment from bluff erosion, two littoral cells were chosen for detailed investigation. The Oceanside and Santa Barbara cells (Figures 8.4 and 8.5) were selected to provide a littoral cell-specific sand budget analysis, including the pre-development budget and the extent of human impact on the budgets.

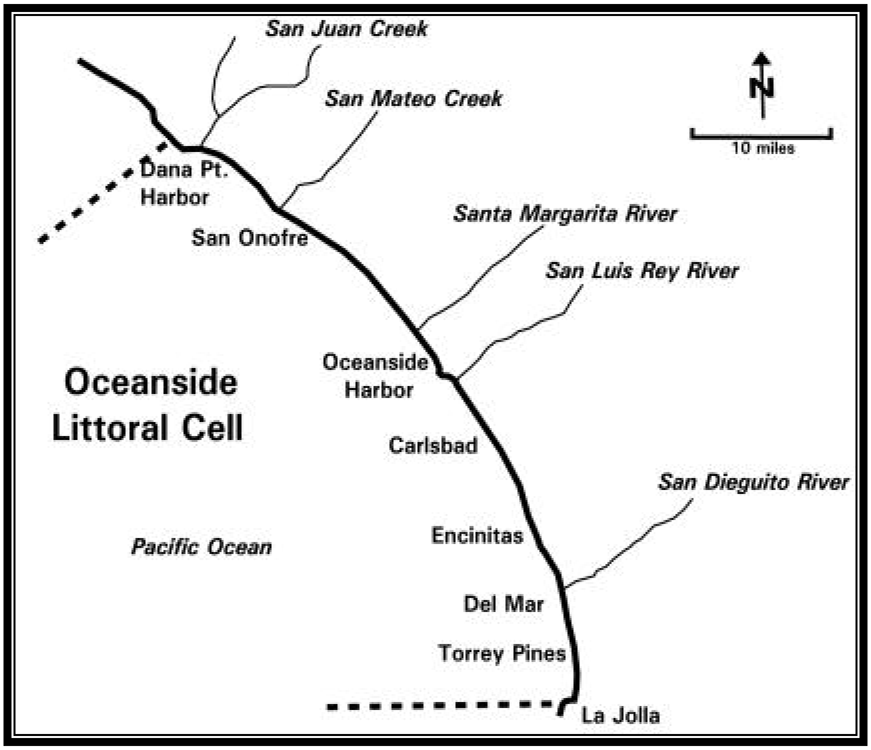


Figure 8.4 Location map for the Oceanside Littoral Cell

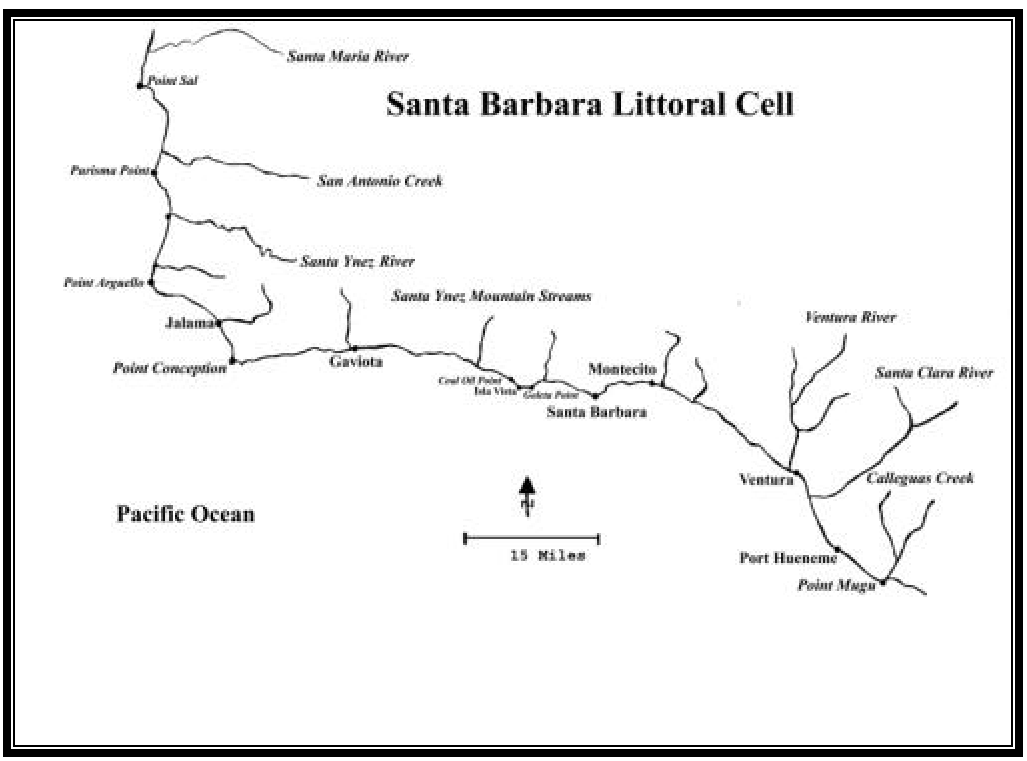


Figure 8.5 Location map for the Santa Barbara Littoral Cell

8.6.1 Oceanside Littoral Cell

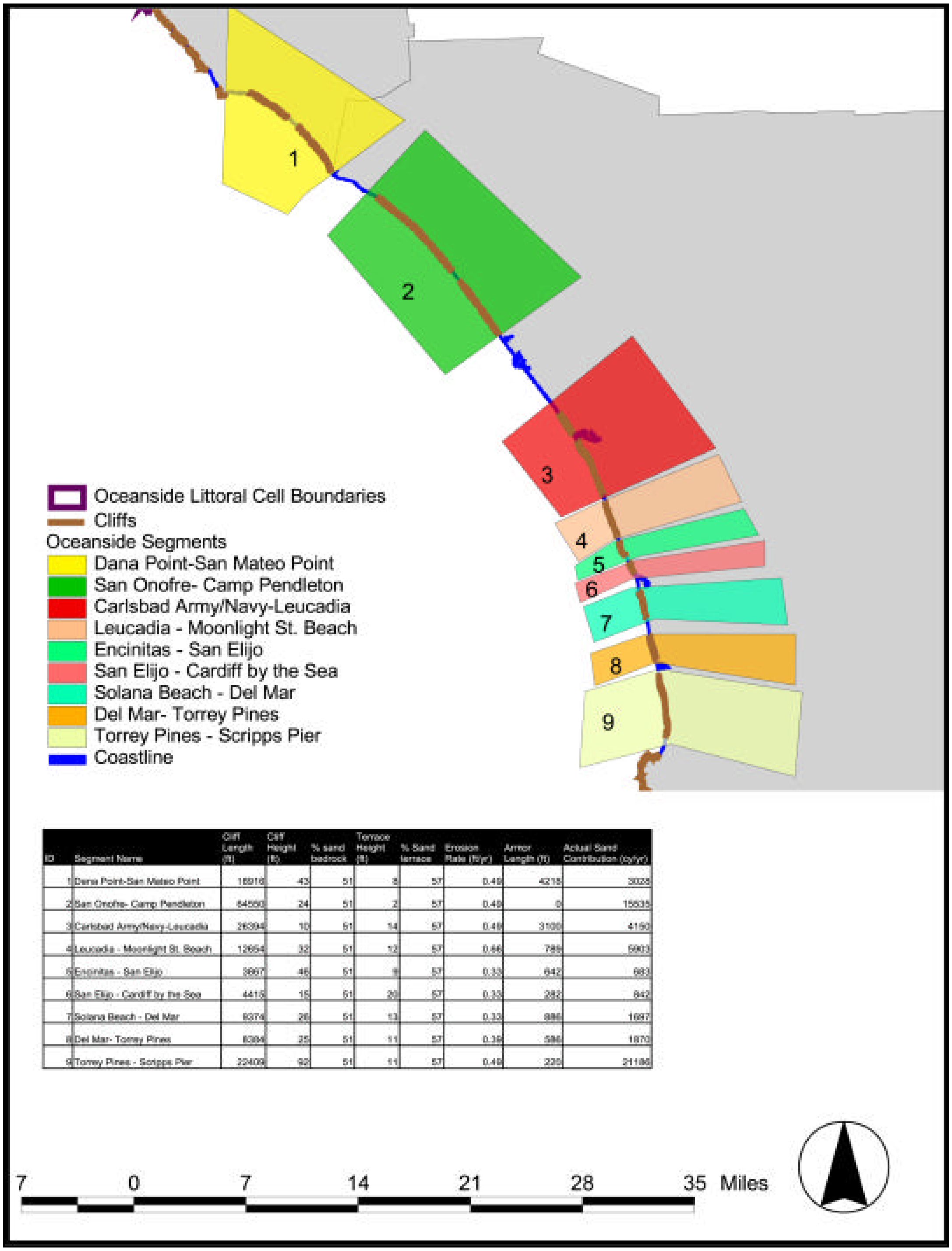
General description of Oceanside littoral cell

The Oceanside littoral cell extends approximately 48 miles (76.5 km) from Dana Point Harbor south to La Jolla Submarine Canyon (Figure 8.4; Inman. and. Frautschy, 1966; Robinson, 1988). The upcoast San Pedro cell terminates at Newport Submarine Canyon, just upcoast of Dana Point. San Juan Creek, San Mateo Creek, the Santa Margarita River, and the San Luis Rey River are the major sources of fluvial sediment input to the Oceanside cell. Sand moves southward in the cell and eventually enters the head of La Jolla submarine canyon, which is within a few hundred yards of the shoreline, just offshore from Scripps Institution of Oceanography. The canyon extends offshore in a southwesterly direction for about 33 miles (53 km), eventually discharging sediment into San Diego Trough.

Plate 8.13 Cliffs at Torrey Pines, San Diego County

Sand contribution from the bluffs of the cell

Seventy-three percent of the Oceanside littoral cell consists of eroding sea cliffs that range in height from 25 to 100 feet (7.5 to 31 m), with the notable exception of the Torrey Pines area where cliffs reach heights of over 300 feet (90 m; Plate 8.13). At most locations in the Oceanside cell, the sea cliffs consist of two units: relatively resistant Eocene bedrock, composed of a variety of sedimentary rocks ranging from mudstone to sandstone and conglomerate, and a capping unit of unconsolidated Pleistocene marine terrace material. More resistant Cretaceous bedrock, which is over 80 million years old, comprises the headlands found from La Jolla to Point Loma. Once eroded, the bedrock and terrace deposits provide a wide range of grain sizes to the littoral budget. By analyzing the grain size distribution of sand on nine beaches in the Oceanside Cell, the littoral cut-off diameter was determined to be approximately .088 mm (3.5 Phi). Annual cliff erosion rates in this littoral cell (Figure 8.2; Figure 8.6), determined by Benumof and Griggs (1999) and Moore, Benumof and Griggs (1998) using soft copy photogrammetry (Moore, 2000) and expressed as weighted averages for distinct segments of the cell, vary from ~ 4 inches (10 cm) to about 8 inches (20 cm) per year depending on the bedrock type, rock strength and structural weaknesses, wave climate, and terrestrial processes.



ID	Segment Name	Cliff Length (ft)	Cliff Height (ft)	% sand bedrock	Terrace Height (ft)	% Sand terrace	Erosion Rate (ft/yr)	Armor Length (ft)	Actual Sand Contribution (cy/yr)
1	Dana Point-San Mateo Point	18916	43	51	8	57	0.49	4218	3028
2	San Onofre- Camp Pendleton	84550	24	51	2	57	0.49	0	15535
3	Carlsbad Army/Navy-Leucadia	26394	10	51	14	57	0.49	3100	4150
4	Leucadia - Moonlight St. Beach	12654	32	51	12	57	0.66	789	5903
5	Encinitas - San Elijo	3867	46	51	9	57	0.33	842	683
6	San Elijo - Cardiff by the Sea	4415	15	51	20	57	0.33	282	842
7	Solana Beach - Del Mar	9374	26	51	13	57	0.33	886	1697
8	Del Mar- Torrey Pines	8394	25	51	11	57	0.39	586	1870
9	Torrey Pines - Scripps Pier	22409	92	51	11	57	0.49	225	21186

Figure 8.6 The Oceanside littoral cell showing segments used in sand contribution calculations

Using the littoral cut-off diameter of .088 mm, it was determined, from the breakdown and grain size analysis of samples collected from the bedrock (7 samples, one of which had an anomalously-low sand content and was eliminated) and terrace deposits (6 samples, one of which had an anomalously-low sand content and was eliminated) from the cliffs of the cell (Appendix B), that these units are comprised of, on average, 51% and 57% respectively of beach-size material.

Using the area of eroding cliff (linear extent and height or thickness of both the bedrock and terrace deposits taken from field measurements), multiplying this by the average percentage of littoral-size material in each geologic unit, and the average annual erosion rates calculated by Benumof and Griggs (1999) and Moore, Benumof, and Griggs (1998), it was determined that the "natural" cliff contribution of sand to the beaches of the Oceanside cell (without taking into account the reduction of sand by armor structures) is approximately 67,300 yds^3 (51,400 m^3) per year.

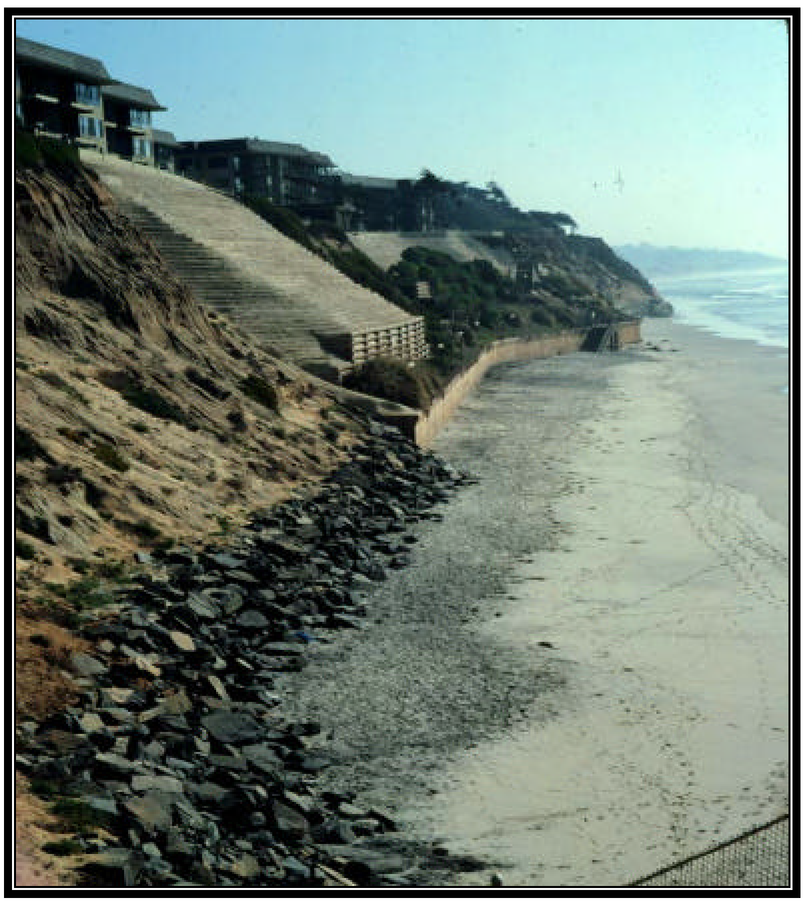


Plate 8.14 Armored bluffs at Del Mar, San Diego County

Extent of coastal protection structures and impact on sand production from cliff erosion

The historical human response to sea cliff erosion in the Oceanside Cell, as well as for most of Southern California, has been to armor the cliff with hard structures (e.g. concrete seawalls, revetments, etc.). In the Oceanside Cell alone, 20% of the sea cliffs have some sort of protective armor (Plate 8.14; Figures 8.7 and 8.8). This armor, while protecting bluff-top development from potential erosion, blocks sand that naturally would be contributing to the littoral budget. By dividing the cell into distinct segments with similar cliff morphology (height/thickness of bedrock and terrace deposits) and erosion rates, we quantified the littoral sand contribution from each coastal segment (Figure 8.6; Table 8.2). By then documenting the extent of bluff armoring for each of these segments (Table 8.2; Figures 8.7 and 8.8), we were able to calculate the amount of littoral material that is prevented by armor from reaching the beach. The armor protecting the bluffs of the Oceanside Cell presently prevents approximately 12,400 yds^3/yr (~9,500 m^3/yr), or 18%, of the "natural" cliff contribution of sand-sized material from entering the littoral cell. As the coastline continues to be armored, the sand provided to the beaches from the cliffs will be reduced further.

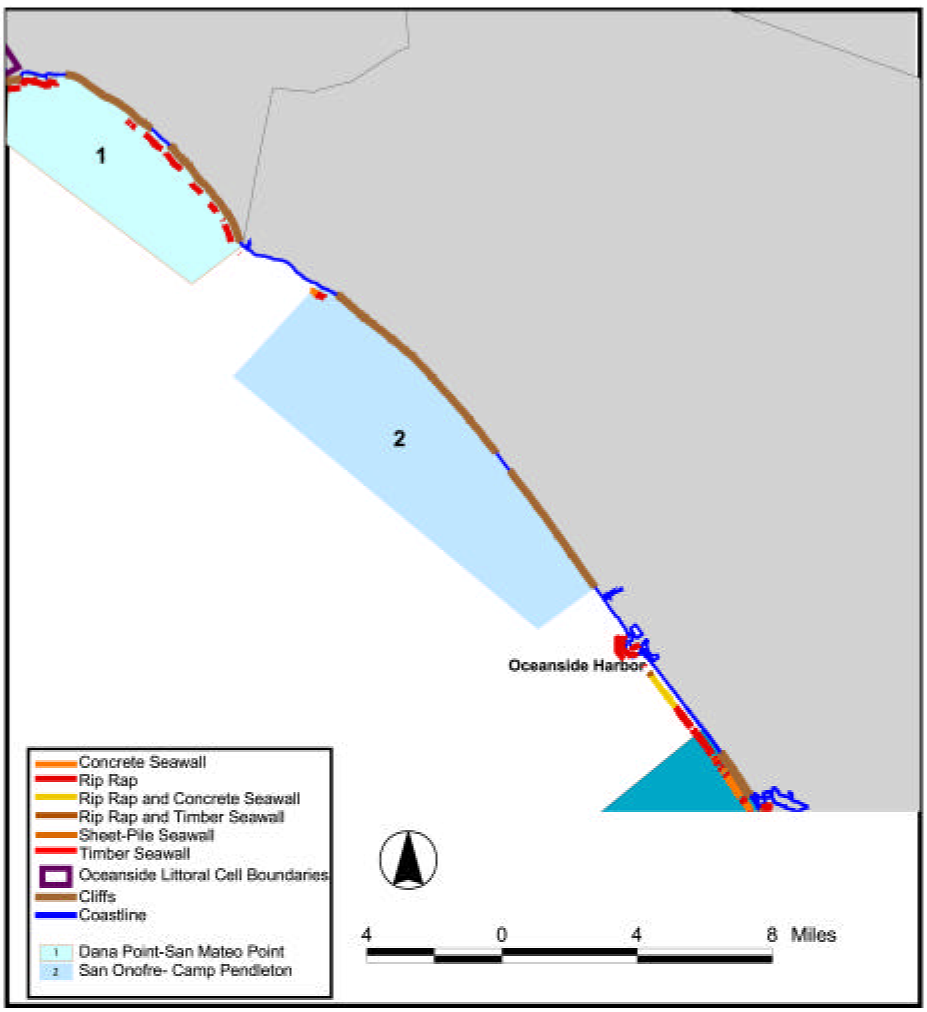


Figure 8.7 Armor in the Oceanside Cell- Dana Point to Oceanside

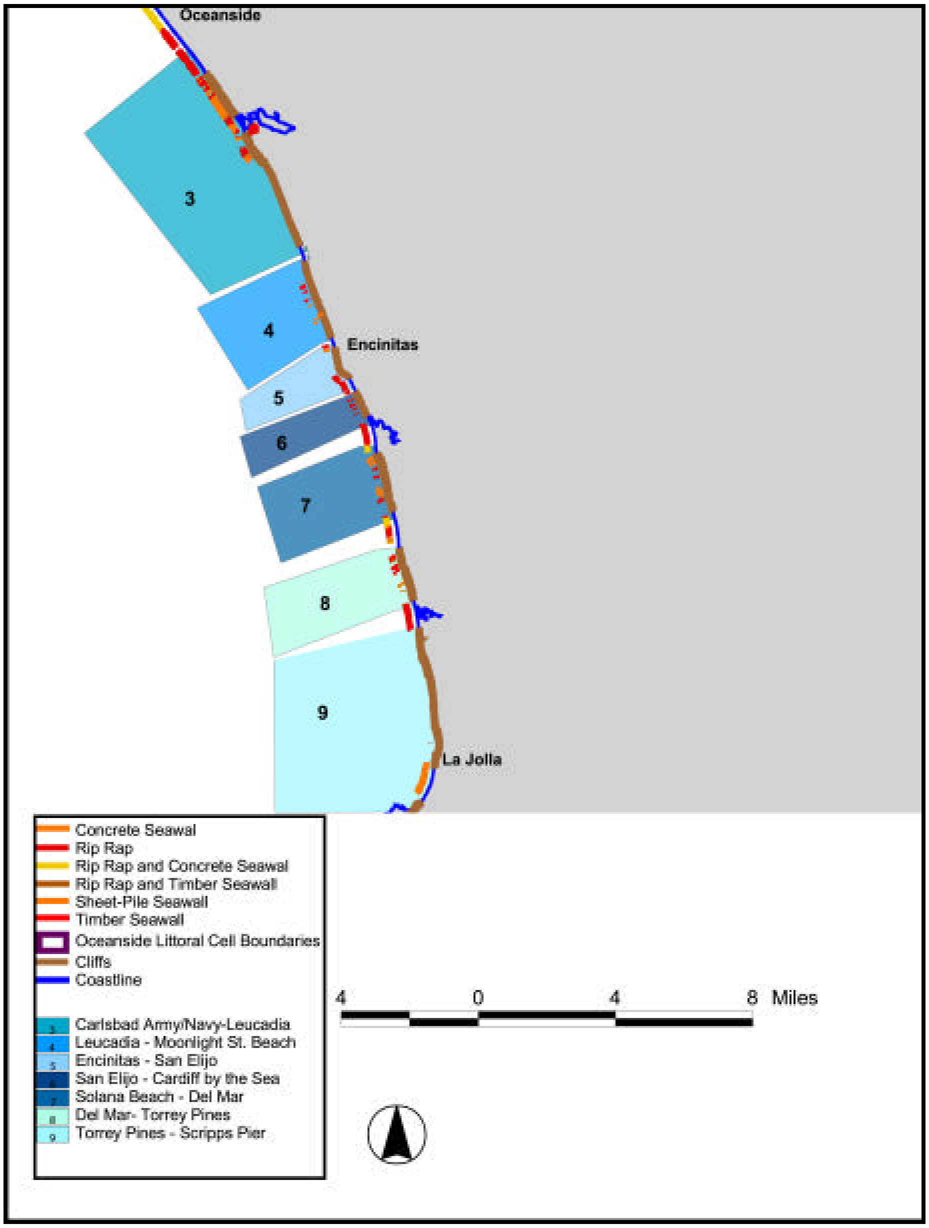


Figure 8.8 Armor in the Oceanside Cell-Oceanside to La Jolla

Impact of bluff armoring on the overall sand budget for the Oceanside littoral cell

In addition to determining the present-day input of littoral sediment to the Oceanside cell from bluff retreat (~54,900 yds^3/yr), we also estimated the sand supplied from stream discharge (~132,000 yds^3/yr: Figure 8.9; Section 7.1, this report); these two sources total ~186,900 yds^3/year.

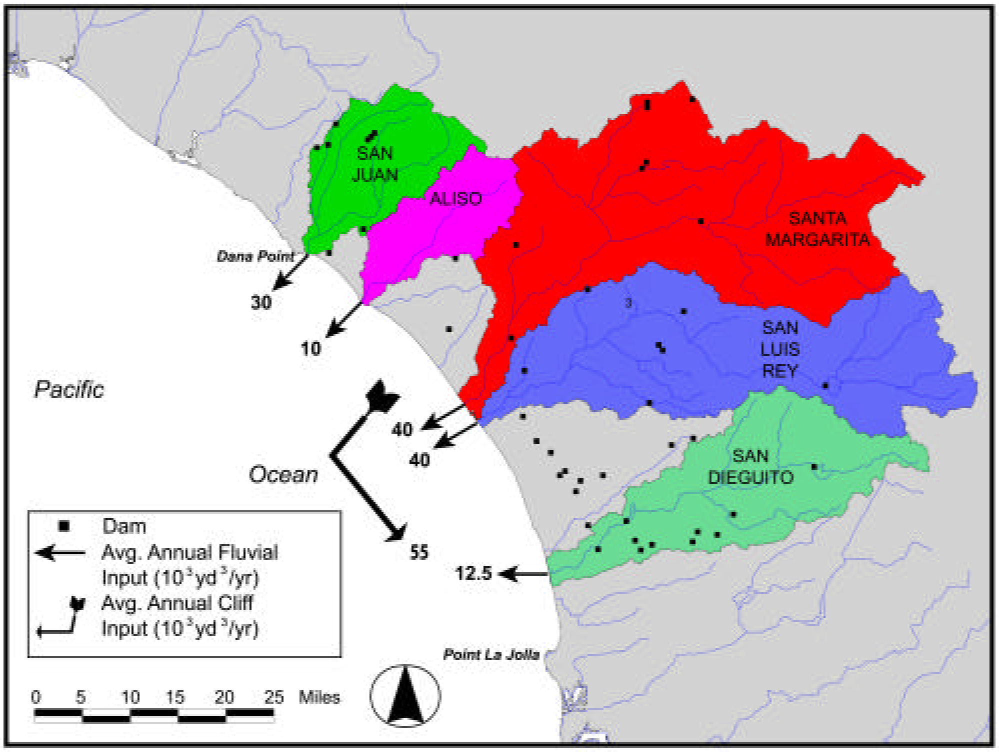


Figure 8.9 Sediment inputs to the Oceanside Littoral Cell

Flick (1994) includes a sand budget for the Oceanside cell that also contains values for both natural and present-day stream delivery, as well as a combined value for cliff retreat, terrace and gully erosion determined by Robinson (1988). In order to arrive at a total sand budget, we need to add the quantity of sand provided by gully and upland terrace erosion that has been deemed by others (Kuhn and Shepard, 1984) to be significant to the cell. To obtain this value, we determined the difference between Robinson's combined cliff retreat, terrace and gully erosion volume (355,000 yds^3/year) and our natural cliff sand contribution volume (67,300 yds^3/year) to arrive at a value for gully and terrace erosion. This component adds an additional 287,700 yds^3/yr.

"Natural" bluff erosion historically has contributed ~10% of the beach sand to the Oceanside cell, with stream input providing 45% and terrace and gully erosion providing the remaining 45% of the sediment reaching the coastline (Table 8.2). The impact of bluff armor on the total sediment contribution for the Oceanside cell is a reduction of 12,400 yds^3/yr, or 3%, of the total littoral budget; at present, the cliffs contribute 11% of the beach sand to the littoral cell, with streams and upland terrace and gully erosion providing the remaining 89% of the total sediment input of 474,533 yd^3/yr.

Table 8.2 Sand Contributions And Reductions Due To Coastal Armoring For The Oceanside And Santa Barbara Cells

CLIFF LOCATIONS	site length		bedrock thickness		% sand	terrace thickness		% sand	erosion rate		natural sand contribution		armor length		actual sand contribution		sand blocked by armor	
OCEANSIDE	meters	feet	meters	feet	bedrock	meters	feet	terrace	m/yr	ft/yr	m^3/yr	cy/yr	meters	yards	m^3/yr	cy/yr	m^3/yr	cy/yr
Scripps Pier to Torrey Pines	6832	22409	28	92	51.10%	3.4	11	57.4%	0.15	0.49	16662.84	21,828	201	220	16,173	21,186	491	642
Torrey Pines to Del Mar	2556	8384	7.7	25	51.10%	3.4	11	57.4%	0.12	0.39	1805.45	2,365	536	586	1,427	1,870	379	496
Del Mar to Solana Beach	2858	9374	8	26	51.10%	3.9	13	57.4%	0.10	0.33	1808.14	2,369	810	886	1,296	1,697	513	671
Cardiff by the Sea to San Elijo State Beach	1346	4415	4.6	15	51.10%	6.2	20	57.4%	0.10	0.33	795.41	1,042	258	282	643	842	153	199
San Elijo to Encinitas	1179	3867	14.1	46	51.10%	2.8	9	57.4%	0.10	0.33	1038.97	1,361	587	642	521	683	518	678
Moonlight state beach to Leucadia	3858	12654	9.9	32	51.10%	3.7	12	57.4%	0.20	0.66	5542.17	7,260	721	789	4,506	5,903	1,038	1,357
Leucadia to Carlsbad Army and Navy	8047	26394	3.1	10	51.10%	4.3	14	57.4%	0.15	0.49	4891.33	6,408	2834.8	3100.2	3,168	4,150	1,726	2,257
Camp Pendleton to San Onofre	19680	64550	7.3	24	51.10%	0.5	2	57.4%	0.15	0.49	11859.07	15,535	0	0.0	11,859	15,535	0	0
San Mateo Point to Dana Point	5767	18916	13.2	43	51.10%	2.3	8	57.4%	0.15	0.49	6976.97	9,140	3856.5	4217.5	2,311	3,028	4,673	6,112
sum											**51,380**	**67,308**	**9,804**	**10,722**	**41,905**	**54,895**	**9,490**	**12,413**
SANTA BARBARA																		
Rincon Point- Loon Point	5540	18,171	30	98.4	0.1%	0.5	1.6	60%	0.305	1.0	557	730	1,804	1,973	376	492	181	238
Loon Point to Fernald Point	2934	9,624	21	68.9	0.1%	1.7	5.6	60%	0.305	1.0	931	1,220	2,087	2,282	269	352	662	867
Fernald Point to SB Cemetary	1350	4,428	29	95.1	0.1%	0.1	0.3	60%	0.305	1.0	37	48	468	512	24	31	13	17
SB Point to Lighthouse	2080	6,822	14	45.9	0.1%	3	9.8	60%	0.152	0.5	575	753	567	620	418	548	157	205
Lighthouse to Arroyo Burro	1995	6,544	14.3	46.9	0.1%	4	13.1	60%	0.152	0.5	734	962	481	526	557	730	177	232
Arroyo Burro to Hope Ranch	4200	13,776	13.7	44.9	0.1%	0.5	1.6	60%	0.152	0.5	201	263	372	407	183	240	18	23
Goleta Beach to Goleta Point	1600	5,248	6.5	21.3	0.1%	3.5	11.5	60%	0.305	1.0	1,027	1,346	345	377	806	1,056	222	290
Goleta Point to Coal Oil Point	1960	6,429	10.2	33.5	0.1%	4	13.1	60%	0.152	0.5	720	943	712	779	458	601	262	343
Coal Oil Point to Naples	7280	23,878	10.2	33.5	0.1%	1	3.3	60%	0.152	0.5	677	887	1,359	1,486	551	721	126	166
Naples to Port Orford	23640	77,539	10.2	33.5	0.1%	1	3.3	60%	0.152	0.5	2,198	2,880	2,566	2,806	1,960	2,567	239	313
Port Orford to Jalama	28331	92,926	6.5	21.3	0.1%	0.1	0.3	60%	0.076	0.2	144	188	3,408	3,727	126	165	17	23
Jalama to Spring Canyon	31596	103,635	7.6	24.9	0.1%	2	6.6	60%	0.076	0.2	2,907	3,809	0	0	2,907	3,809	0	0
sum											**10,708**	**14,028**	**14,169**	**15,495**	**8,635**	**11,312**	**2,073**	**2,716**

8.6.2 Santa Barbara Littoral Cell

General description of cell--extent, inputs and outputs

The Santa Barbara littoral cell is one of the longest littoral cells in Southern California, extending, for the purposes of our study, 143 miles (230 km) from the mouth of the Santa Maria River, around Point Conception, and terminating at Point Mugu into the Mugu Submarine Canyon (Figure 8.5). At Point Conception, the California coastline makes an abrupt 90-degree shift from a north/south orientation to an east/west orientation. The Santa Maria, Santa Ynez, Ventura and Santa Clara rivers all provide significant volumes of sand to the cell. For this study, the coastline in the cell has been divided into segments (Figure 8.10) in order to better identify the inputs to the littoral budget.

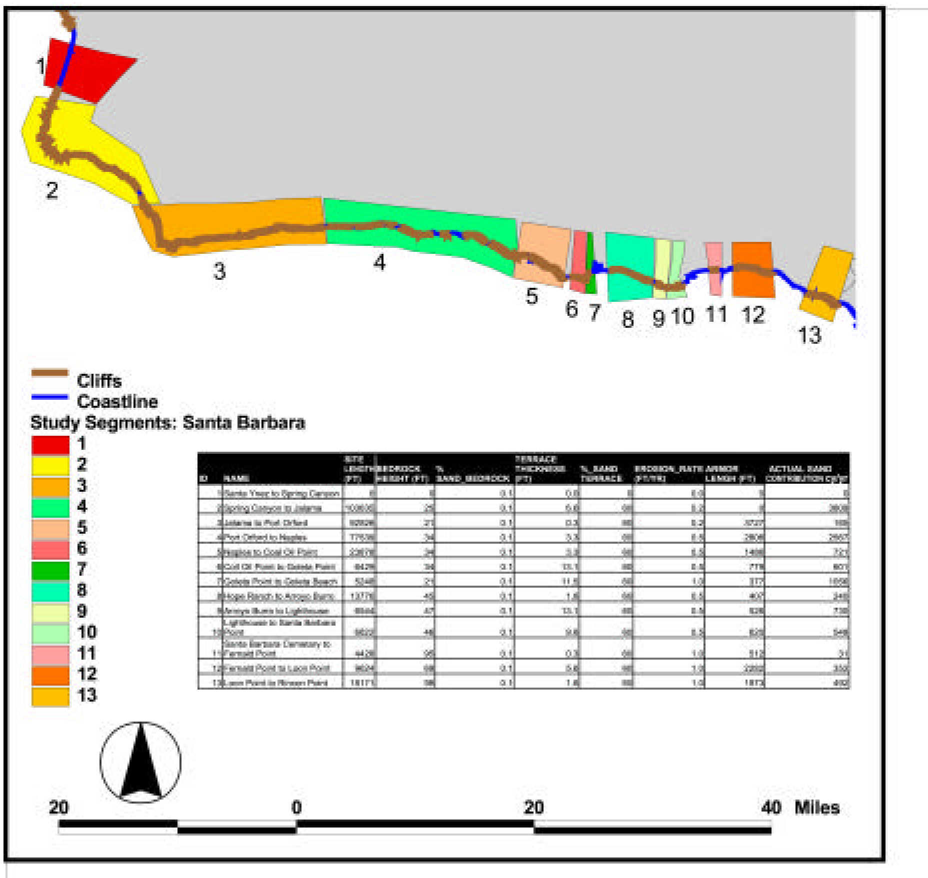


Figure 8.10 The Santa Barbara Littoral Cell showing individual segments used in sand contribution calculations

The Santa Maria River mouth was selected as the upcoast boundary for the Santa Barbara littoral cell. The large dune fields north of the river mouth suggest that most of the upcoast littoral sand is lost to inland sources at this location. There are two major rivers that deliver sediment to the coast north of Pt. Conception. Willis (Section 7.1, this study) calculates that the Santa Maria River produces ~260,000 yds^3/yr of sand and the Santa Ynez River produces about 347,000 yds^3/yr. While there are no submarine canyons to serve as sinks upcoast from Pt. Conception, the littoral budget analysis carried out by Bowen and Inman (1966) calculated, using field observations and reasonable assumptions, that ~106,000 yds^3/yr of sand were lost to the extensive dune fields south of the Santa Maria River (Figure 8.11). The average annual sand discharge for the Santa Maria River, San Antonio Creek and the Santa Ynez River totals ~668,000 yds^3 (Section 7.1, this study). Losses to the dunes remove ~106,000 yds^3/yr leaving a net of 562,000 yds^3/yr of littoral sand in transit towards Pt. Conception.

It has long been debated (USACOE, 1955; Azmon, 1960; Bowen and Inman, 1966; Duane and Judge, 1969; Judge 1970; Pollard, 1979; Diener, 2000) whether sand from the Santa Ynez and Santa Maria rivers moves around Point Conception to contribute sand to the Santa Barbara littoral cell, or whether Pt. Conception forms a littoral drift barrier.

Plate 8.15 Cliffs north of Goleta Point, Santa Barbara County

In 1952, Trask examined the heavy minerals of beaches and streams between Monterey Bay and Santa Barbara and also investigated the question of whether sand moves around promontories along the California shoreline. Trask (1955) studied the Pt. Conception area as well as several other promontories in Southern California. The initial evidence he encountered that indicated that littoral sand does move around Pt. Conception was the presence of the mineral augite in the beach sands at Santa Barbara. While the augite concentration was only 3%, this percentage increased up coast to 10% at Pt. Conception and 50% north of Pt. Conception near the Santa Maria River. Stream sediment samples taken between Santa Barbara and Pt. Conception contained no augite, and Trask concluded that the cliffs along this coast (Plate 8.15) were not eroding at a rapid enough rate to provide the 1000 yds^3/day (~760 m^3/day), on average, of sand that was moving alongshore. He also found that the cliffs contained no augite. A combination of beach and nearshore profiles, diver observations and sediment analyses were used to conclude that the sand on the beaches of Santa Barbara was being transported from north of Pt. Conception and then eastward alongshore to Santa Barbara. Trask found that active bypassing of the point occurs in a zone out to a depth of 33 ft (10m) and that some movement also takes place to a depth of 66 ft (20m).

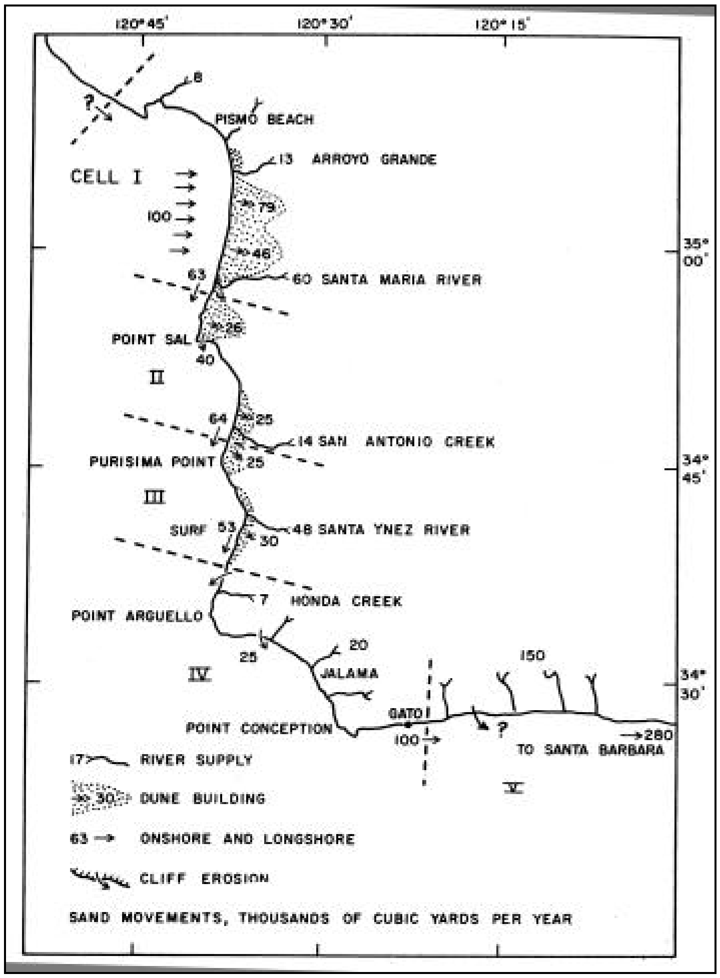


Figure 8.11 Sand budget for the Santa Barbara Littoral Cell (Bowen and Inman, 1966)

Studying heavy mineral assemblages in beach and offshore samples between Surf (north of Pt. Conception) and the Mexican border, Azmon (1960) also found greater amounts of augite north of Pt. Conception than east of it. On this basis, he concluded that the Point acts as at least a partial barrier to sediment movement. The generalized littoral budget developed by Bowen and Inman (1966) for the Pt. Arguello to Santa Barbara area also indicates that sand moves downcoast and around Pt. Conception and then continues to Santa Barbara (Figure 8.11). Judge (1970) concluded, based on sand tracer experiments in the vicinity of Pt. Arguello and Pt.

Conception, and from other evidence, that while this headland complex may act as a partial barrier, some sand does in fact move south and east around Pt. Conception.

Table 8.3 Is Pt. Conception a sediment barrier?

Researcher	Year	Method	Conclusion: Is sand moving around Point Conception?
Trask	1952	Heavy Mineral Tracer	Yes: Point Conception is a partial barrier, but sand is moving around it.
Azmon	1960	Heavy Mineral Tracer	Yes: Point Conception is a partial barrier, but sand is moving around it.
Bowen and Inman	1962	Sediment Budget	Yes: Point Conception is a partial barrier, but sand is moving around it.
Judge	1970	Sand Tracer	Yes: Point Conception is a partial barrier, but sand is moving around it.
Diener	2000	Sediment Budget	No

More recently, Diener (2000) studied the input of sand to the Santa Barbara littoral cell from the coastal bluffs between Pt. Conception and the Santa Barbara harbor and assessed the possibility that sediment travels around Pt. Conception. He used estimates of the annual volume of littoral sand entering the Santa Barbara harbor (Johnson, 1953) and estimates of stream and gully sediment input between Pt. Conception and Santa Barbara from Bowen and Inman (1966), combined with calculations of sediment input from the sea cliffs, to conclude that the cliffs provided the material needed to balance the littoral budget. Diener's conclusions, however, and the littoral budget he developed were evaluated carefully because they are in disagreement with previous research and budgets that concluded that sand is contributed to the Santa Barbara Cell by the area north of Pt. Conception (Table 8.3). Diener's calculations and littoral budget numbers are analyzed below.

Littoral transport at the Santa Barbara Harbor. Because the Santa Barbara breakwater (Plate 8.16) essentially serves as a complete trap for littoral transport at this point in the cell, the yearly dredging numbers from the harbor should provide a good measurement of annual littoral drift rates. Diener used a value from 1953 of 280,000 yds^3/yr (212,000 m^3/yr; Johnson, 1953) for the littoral transport rate. Average annual dredging values in recent years, however, which are more representative of present conditions, indicate a higher value. For the last 15 years (1986-2001), the annual dredging rate has averaged 357,000 yds^3/yr (270,000 m^3/yr; Myerson, 2001).

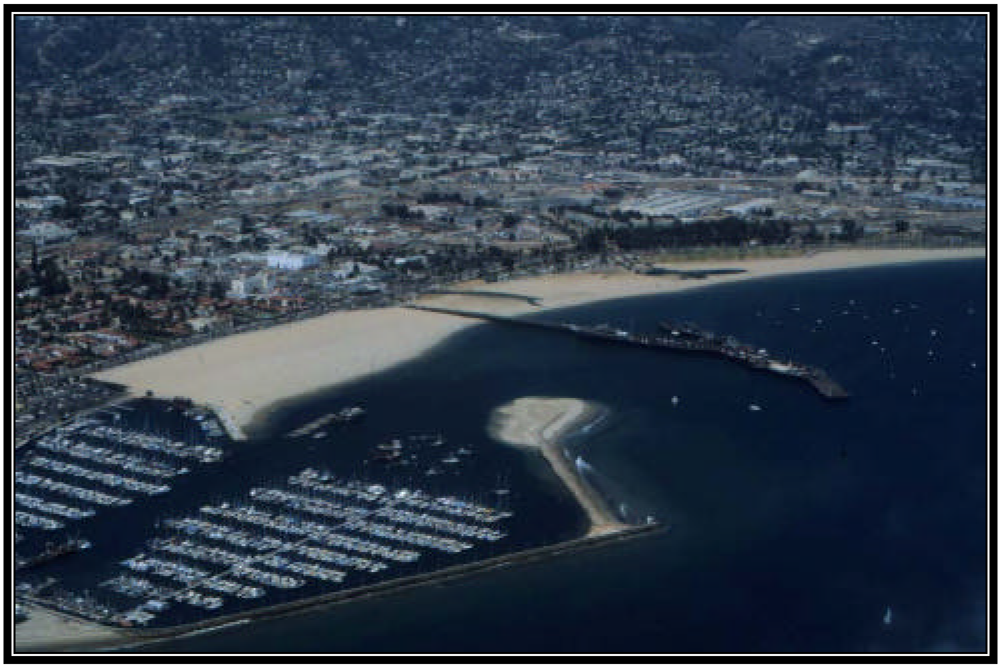


Plate 8.16 Santa Barbara breakwater and sand spit

Stream contributions between Pt. Conception and Santa Barbara: In Bowen and Inman's (1966) littoral budget for the Central California coast between Pismo Beach and Santa Barbara, they determined sand inputs and outputs. Based on sediment yield estimates from Johnson (1959), who used the Einstein bed load formula, Bowen and Inman estimate an annual contribution for the Santa Ynez River, and state that "*the series of small creeks between Pt. Arguello and Santa Barbara should have the same yield as the Santa Ynez River before flood control, some 700 yds^3/mi^2/yr*." In their budget, they presumably take the total drainage area for these small watersheds and, using this estimated value, arrive at a value for stream contribution between Pt. Conception and Santa Barbara of 150,000 yds^3/yr. Diener (2000), does not discuss or qualify the nature of these estimates, but uses the value (which is mistakenly reported as 170,000 yds^3/yr) in his budget. Willis (Section 7.1, this report), using updated stream flow, sediment discharge and reservoir filling data, has recently recalculated the input of littoral sediment from the Santa Maria River, the Santa Ynez River, San Antonio Creek and also the streams draining the Santa Ynez Mountains between Pt. Conception and Santa Barbara to arrive at a total of 864,000 yds^3/yr from fluvial sources along this coastal segment.

Cliff contributions from Pt. Conception to Santa Barbara: Utilizing the Santa Barbara harbor dredging numbers published by Johnson in 1953 (280,000 yds^3/yr) and subtracting 170,000 yds^3/yr (130,000 m^3/yr) as an estimate of sand contributed from the upcoast streams, Diener (2000) reasoned that "*if the combined inputs from streams and gullies, and from bluff erosion, balances the 280,000 yds^3 (Johnson, 1953) of sand estimated to enter the harbor annually, it can be assumed that sand is not entering from any other source*". Diener then measured the area of the coastal bluff frontage between Pt. Conception and Santa Barbara harbor, determined bluff erosion rates for individual segments using USGS topographic sheets and recent aerial photos, and calculated the percentage of sand in the bluff materials in order to derive an annual sand volume contribution to the beaches of 106,000 yds^3/yr. Combining the fluvial input of 170,000 yds^3 and the calculated bluff erosion input of 106,000 yds^3 produced a total yield of 276,000 yds^3/yr , or nearly the same value quoted from Johnson (1953) for sand transport at the Santa Barbara harbor. There are concerns, however, with the sand percentages reported for the bluff materials and also with the methods used for determining bluff erosion rates, which significantly affect the importance of bluff erosion along this stretch of coast to the littoral budget.

Sand content of the bluff materials

The cliffs between Pt. Conception and the Santa Barbara harbor are 10-100 feet (3 – 30 m) in height and are cut into an uplifted marine terrace (Plate 8.17). The sea cliffs expose a basal bedrock unit (either the Monterey Shale, which is a Miocene marine shale, or the Sisquoc Formation, a diatomaceous silty shale) and an overlying sequence of unconsolidated marine terrace deposits and soils, ranging in thickness from 6 to 52 feet (2 to 16 m). Diener collected sediment samples from 32 different sites between Pt. Conception and Santa Barbara and reported "*the percentage of bluff material that was sand-sized was determined by sieve analysis for each. Each percentage was determined from a combination of each formation taken within the study area*". Diener reported that the average sand content was 34.1% for the Monterey shale, 21.9% for the Sisquoc Formation, and 62% for the terrace deposits. These values were then combined with the area and erosion rate determined for each segment of bluff to provide a total sand contribution for the entire length of the bluff.

Plate 8.17 Eroding bluffs between Goleta Point and Coal Oil Point

Due to the high sand contents reported by Diener for two shale formations, we re-sampled the Monterey, Sisquoc and terrace deposits as part of this investigation. After attempting to break down the shale by a combination of hydrogen peroxide and some grinding, which still left large shale fragments, we put ~50 to 100 grams of the broken-up shale samples into a rock tumbler with an equal amount of beach sand and water, in order to simulate the abrasion process that goes on in the surf zone. We tumbled the samples for 12 to 24 hours and then washed the sediment through a 0.062 mm sieve to determine the amount of sand-size material remaining after subtracting the weight of the beach sand added for abrasion. In some cases, where the shale was very hard, there were still some larger fragments remaining (coarser than 1 mm). The weight of the shale fragments remaining was subtracted from the initial sample weight, and then the amount of sand that was derived from the bedrock or terrace sample breakdown was then converted to a percentage of littoral-size material.

While there may have been, on average, 34.1% of the ground-up shale that remained on a 0.062 mm (sand-size) sieve in Diener's grain size analysis, we believe that this was most probably shale fragments that would be broken down into clay and dispersed quickly in the surf zone. No littoral-size material resulted from the breakdown and analysis of any of the eight samples we collected from the Monterey Shale and Sisquoc Formation making up the bluffs between Goleta and Jalama, just north of Pt. Conception (Table 8.2). Thus, we conclude that the bedrock material exposed in the cliffs between Pt. Conception and Santa Barbara is not a significant contributor to the sand budget in this cell. One bedrock sample from the current study did contain 16% littoral-size material. It was collected from Pt. Santa Barbara, near the Santa Barbara Harbor. This point consists of the Santa Barbara formation, which does contain sand but has only a very limited coastal outcrop area.

Diener also determined the sand contribution from the terrace deposits, which averaged 62% sand. Terrace samples were sampled and analyzed in this study from six locations extending from Jalama to Rincon Point, north of Ventura. With the exception of one anomalous very fine-grained terrace sample from the Isla Vista area, the terrace samples averaged 60% littoral-size sand, very comparable to the value Diener obtained. These samples were unconsolidated, however, so no significant disaggregation was required.

<u>Erosion rates and sand contributions</u>

Unfortunately, erosion rates for the bluffs in the Santa Barbara cell are not well documented (Figure 8.2). In *Living with the California Coast* (Griggs and Savoy, 1985), sixteen erosion rates throughout the length of the cell were reported. These rates range from 3 inches (7.6 cm) per year in the Jalama area to 12 inches (30.5 cm) per year near Rincon, overall a relatively narrow range (Table 8.2).

Using the methods outlined in Section 8.4.1 of this report, the overall "natural" sand contribution from bluff erosion for the entire Santa Barbara Littoral Cell is estimated to be 14,000 yds^3/yr (10,700 m^3/yr) (Table 8.2).

In 1989, Noble Consultants estimated that the coastal bluffs from Coal Oil Point (Goleta) to Point Mugu contributed approximately 10,000-15,000 yds^3/yr (8,000-11,000 m^3/yr) of sand to the shoreline. Sea cliffs along this stretch of coastline range in height from 10 to 100 feet (3 to 30 m), and consist predominantly of Monterey and Sisquoc Formations capped by 2 to 20 feet unconsolidated terrace deposits. Noble Consultants based the contribution of sand-sized material emanating from sea cliffs in the Santa Barbara littoral cell on work done by Pollard (1979) on the cliffs west of the Santa Barbara Harbor. Pollard assumed a uniform bluff retreat rate of 0.5-1 ft/yr, an average cliff height of 40 ft, and a 60% sand contribution from the cliffs to end up with 73,000 yds^3/yr (95,000m^3/yr) of beach size material coming out of the sea cliffs from Point Conception to Goleta Point. Noble Consultants developed a unit source volume rate by dividing Pollard's estimated quantity by the number of applicable shoreline miles. This leads to a volume of 2,000 cubic yards of sand, per mile of beach, emanating from bluff erosion; thus, they assume that the cliffs between Goleta Point and Santa Barbara harbor produce another 10,000-15,000 yds^3/yr of sand.

The segment of the Santa Barbara cell analyzed by Noble Consultants does not include the coast from Coal Oil Point to Spring Canyon, north of Pt. Conception; however when they added their 10,000-15,000 yds^3/yr of sand to the cliff contribution calculated by Pollard (73,000 yds^3/yr) from Point Conception to Goleta Point, the estimated value of cliff input is considerably higher than our calculations (Noble: 90,000 yds^3/yr; this study: 14,000 yds^3/yr) for the Santa Barbara littoral cell. The discrepancy between the Noble Consultants (1989)/ Pollard (1979) study and the results from the present study is due to the percent of beach-size material found in bedrock and terrace materials; Pollard and thus Noble Consultants assume a uniform contribution of 60% sand composition of cliff material, while we found a 0.1% sand composition in the bedrock and 66% sand composition in the relatively thin overlying terrace material.

Plate 8.18 Bluff erosion in Isla Vista, Santa Barbara County

Extent of coastal protection structures and impact on sand production from cliff erosion

Bluff failures have been devastating to many cliff-top developments in the Santa Barbara Cell, including Channel Drive, Del Playa, El Camino, Cliff Drive, and Isla Vista (Plate 8.18). As with the Oceanside Littoral Cell and most of Southern California, the typical response in the past to the threat of bluff failure has been the construction of hard protection structures (Figures 8.12 and 8.13). Sea walls, rip-rap or other armoring, including breakwaters, now protect 44% or 33 miles (52.8 km) of the coastline of the Santa Barbara cell. Only 11 miles of this armoring is protecting sea cliffs, however; the remaining armor is protecting beaches and harbors and is not impacting the natural sand supply to the coast from cliff erosion. The shore-parallel armor is estimated to be preventing approximately 2,700 yds^3/yr (2,000 m^3/yr) of sand from ending up on the beaches of the cell (Table 8.2). This represents 19% of the original or "natural" contribution to the littoral budget from bluff erosion.

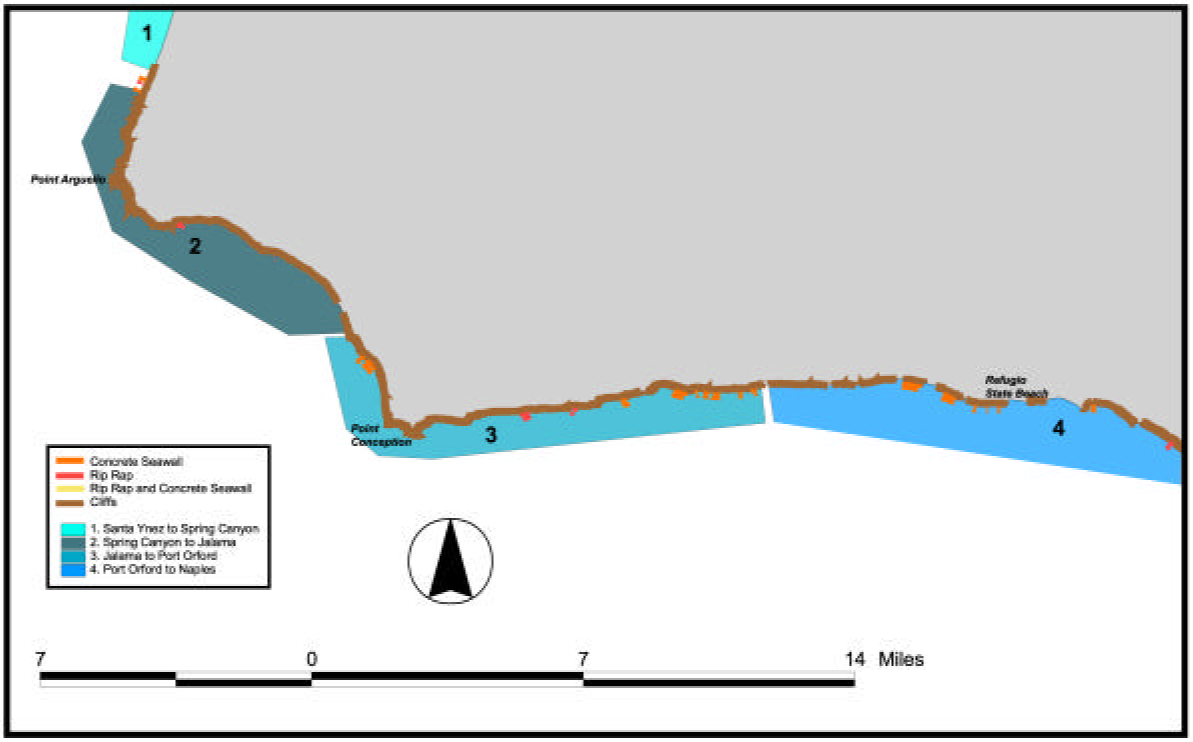


Figure 8.12 Armor in the Santa Barbara Cell-Spring Canyon to Naples

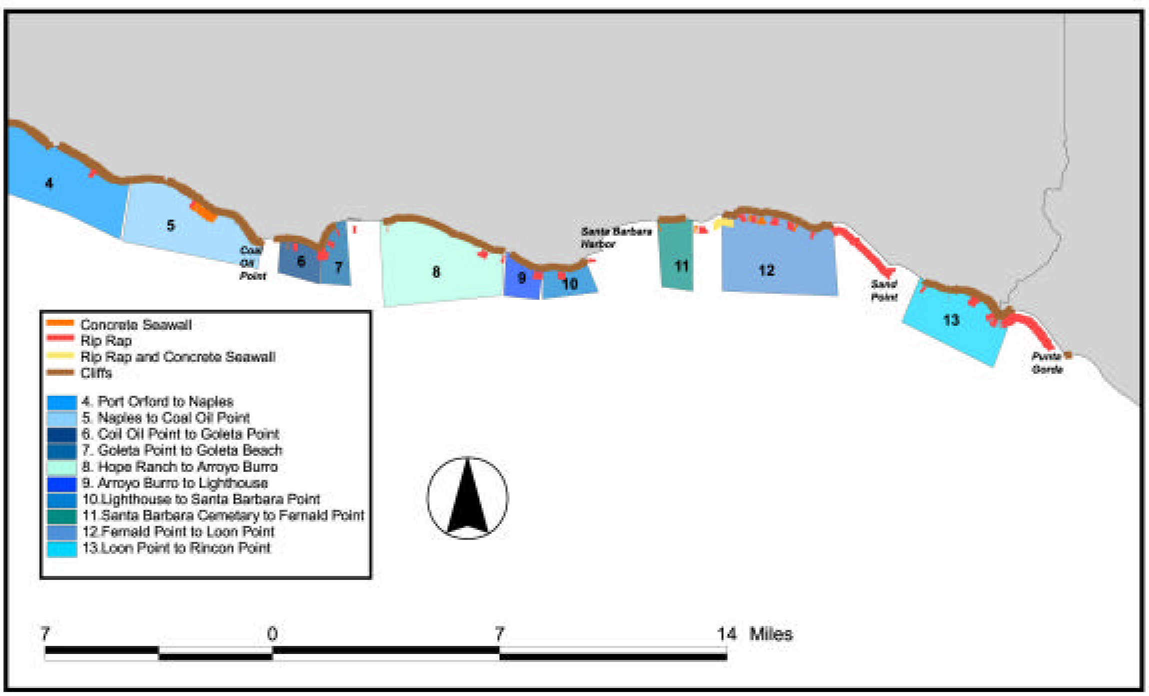


Figure 8.13 Armor in the Santa Barbara Cell-Naples to Punta Gorda

Sediment inputs to the Santa Barbara Cell and human impacts

It is important to evaluate the significance of the reduction of littoral sand through bluff armoring to the entire budget of the Santa Barbara littoral cell. There have long been concerns with both bluff erosion and perceived beach erosion in the down coast portion of the cell. The construction of the harbors at Santa Barbara, Ventura and Channel Islands as well as dams on the Ventura and Santa Clara rivers and the armoring of the bluff have all affected the overall sand budget.

We have updated the sand inputs for the Santa Barbara cell based on the most recent calculations or measurements of river discharge, cliff erosion and harbor dredging (Figure 8.14; gully erosion is not a significant source of beach sediment in the Santa Barbara cell). The present-day average annual sand input from the streams into the cell total ~ 2,167,000 yds^3/yr, and include the following (Section 7.1, this report):

- Santa Maria River: ~261,000 yds^3
- San Antonio Creek: ~60,000 yds^3
- Santa Ynez River: ~347,000 yds^3
- Streams between Pt. Conception and Santa Barbara: ~196,000yds^3
- Ventura River: ~103,000 yds^3
- Santa Clara River: ~1,200,000 yds^3

Total natural input from bluff erosion was ~14,000 yds^3/yr, which has been reduced to ~11,300 yds^3/yr due to construction of coastal armoring structures.

Littoral sand inputs to the Santa Barbara cell at present total 2,167,000 yds^3/yr, of which stream input contributes 99.5% with bluff erosion contributing the remaining 0.5%. Prior to armoring and dam construction, the cliffs contributed 0.4% of the entire sand supply to the cell. Bluff armoring has reduced the total sand input to the Santa Barbara cell by 2,716 yd^3/yr or 0.1% of the total budget.

Estimates of littoral sand contribution to the cell can be evaluated by looking at the sand budget at a specific location within the cell, such as the Santa Barbara harbor (Plate 8.16). Average annual present-day upcoast sand inputs include 864,000 yds^3 of stream input and 10,400 yds^3 of bluff input, for a total of 874,400 yds^3/yr. Approximately 106,000 yds^3/yr of sand are lost to the dunes north of Pt. Conception every year, resulting in an annual littoral drift volume of 768,400 yds^3 up coast of the harbor. The average annual maintenance dredging volume at the Santa Barbara harbor (357,000 yds^3; Myerson, 2001), however, is 411,400 yds^3 lower than the sediment input volume. This is a very large volume discrepancy, which could be accounted for by a combination of 1) significant volumes of littoral sand not being transported around Pt. Conception, as others have concluded; 2) significant volumes of sand bypassing the Santa

Barbara harbor and therefore not being included in the annual dredging volumes; and 3) uncertainties in the calculations of the sediment inputs from the streams in the cell.

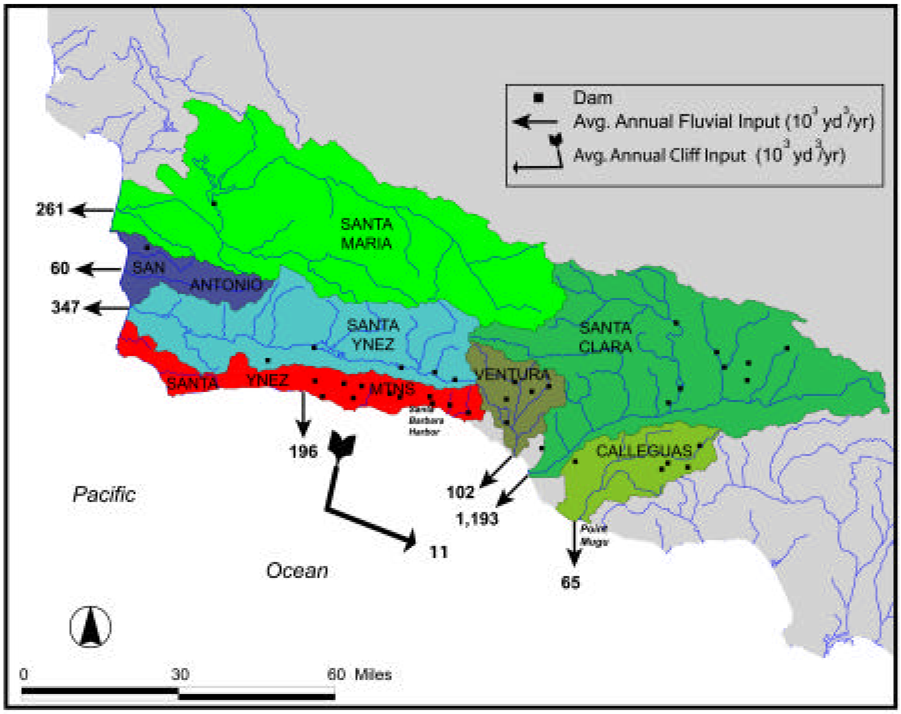


Figure 8.14 Sediment Inputs to the Santa Barbara Littoral Cell

8.7 Discussion

The Santa Barbara and Oceanside littoral cells were selected for detailed sediment input analysis because their beaches are intensively-used recreational areas and there have been concerns expressed in recent years regarding narrowing or erosion of the beaches. In both cells, coastal bluff development is both dense and threatened by bluff erosion, leading to the wide use of armor to protect the bluffs. The objectives of this portion of the study were to assess the degree to which coastal bluff protection structures have reduced the supply of sand to these littoral cells and to make any appropriate recommendations for future action or policy that might lead to an increase in the natural sediment supply to the coast.

***Santa Barbara Cell*:** The Santa Barbara littoral cell is 144 miles in length and cliffs make up 78 miles or 54% of the coastline of the cell. Most of the cliffs have been cut into uplifted marine terraces by wave action (Plate 8.15). In order to reduce bluff erosion and protect coastal development, 11 miles or 14% of the cliffs in the cell have now been armored. A sediment input analysis for the entire cell indicates that, prior to construction of any dams, streams contributed approximately 3,642,773 yds^3/yr on average; this has now been reduced ~ 40.5% to 2,167,000 yds^3/yr (Table 8.4; Section 7.2, this report). This represents an average annual reduction of

~1,475,773 yds^3/yr for the entire cell. Coastal bluff erosion naturally provided ~ 14,000 yds^3/yr and this has been reduced 19.3% to 11,300 yds^3/yr through the emplacement of coastal armoring. This represents a reduction of 2,700 yds^3/yr.

Table 8.4 Sediment Inputs to the Oceanside and Santa Barbara Littoral Cells

Oceanside Littoral Cell			
Inputs	**Natural (cy/yr)**	**Actual (cy/yr)**	**Reduction (cy/yr)**
Rivers	286,500 44.7%	132,500 27.9%	154,000 53.8%
Bluff Erosion	67,300 10.5%	54,900 11.6%	12,400 18.4%
Gullies/Terraces	287,000 44.8%	287,000 60.5%	0 0.0%
Total Littoral Input	640,800 100.0%	474,400 100.0%	166,400 26.0%
Santa Barbara Littoral Cell			
Inputs	**Natural (cy/yr)**	**Actual (cy/yr)**	**Reduction (cy/yr)**
Rivers	3,642,773 99.6%	2,167,000 99.5%	1,475,773 40.5%
Bluff Erosion	14,028 0.4%	11,312 0.5%	2,716 19.3%
Total Littoral Input	3,656,801 100.0%	2,178,312 100.0%	1,478,489 40.4%

Overall, of the historic or natural littoral sediment inputs to the Santa Barbara cell, streams contributed 99.6% of the sand, while bluff erosion contributed only 0.4% (Table 8.4; Figure 8.14). Today, bluffs contribute 0.5% of the total littoral sand and the effect of armoring the 11 miles of seacliffs in the cell has been a total reduction in the littoral sand supply of ~ 0.1%.

***Oceanside Cell*: The Oceanside Littoral Cell is about 48 miles in length and cliffs or bluffs make up 35 miles, or 73%, of the coastline. Throughout much of this cell, as with the Santa Barbara cell, the cliffs have been eroded into uplifted marine terraces that have been extensively developed (Plate 8.19). Seven miles, or 20%, of the bluffs of the cell have now been armored. A sand input analysis for the entire littoral cell indicates that streams historically provided ~286,500 yds^3/yr, on average, and that dams have reduced this input to 132,500 yds^3/yr (Section 7.2, this report). This represents an average annual reduction of ~ 154,000 yds^3/yr. Bluff erosion prior to the emplacement of seawalls and rip-rap contributed an additional 67,300 yds^3/yr (Tables 8.2 and 8.4) and this has been reduced to 54,900 yds^3/yr due to bluff armoring. Thus, armoring has reduced the sand input to the cell by ~12,400 yds^3/yr

Previous research in this cell indicates that gully erosion and subaerial erosion of the uplifted marine terraces contribute ~287,700 yds^3/yr, for a total natural sand input to the Oceanside cell of ~ 640,800 yds^3/yr (Table 8.4). Thus, bluff erosion historically contributed 10.5% of the sand to the Oceanside cell, streams contributed 44.7%, and gully erosion and upland terrace degradation made up the remaining 44.8%.

Plate 8.19 Blufftop development in the Leucadia area of the Oceanside Cell

The construction of dams has reduced stream input by ~154,000 yds^3/yr, and the emplacement of armor now has reduced the sand input from bluff erosion by ~12,400 yds^3/yr. Bluffs now contribute 11.6% of the total littoral sand to the cell and the effect of armoring seven miles of bluffs in the cell has been to reduce the total littoral budget by about 2%.

Recommendations for the Future

The construction of dams and coastal armor structures have reduced the total sand supply to the Santa Barbara and Oceanside littoral cells by an estimated 40.4% (1,478,489 yds^3/yr) and 26.0% (166,400 yds^3/yr), respectively. These are significant human modifications of large natural systems, although the long-term effects of these source reductions have not yet been quantified. While there is considerable anecdotal information, as well as observations and photographic records, about shoreline erosion and coastal storm damage in both cells, there are no long-term (50 years or more) documented or published records of systematic changes in beach width or volume. Long-term changes in beach width need to be quantified, evaluated and then compared to the calculated reductions in littoral sand supply to both cells in order to confirm the correlation between the two phenomena. Specifically, has the reduction in the calculated sand input from a particular stream or at a specific location in the cell produced a related long-term reduction in beach width or volume downdrift of that location?

Although the values calculated and included in this report for both historic or natural and present-day quantities of littoral sand supplied by streams, bluff erosion, and terrace and gully erosion are precise, it is important to keep in mind the uncertainties involved in determining these values. An analysis of the errors associated with the values used in this report is included in Appendix D.

Another important factor to consider in evaluating the values calculated for sand input from streams and the reduction in these values due to dam construction is the connectivity between the upstream gauging station or location where the sediment discharge was determined and the shoreline. Many of these streams cross broad alluvial valleys prior to arriving at the shoreline, and much of the sediment measured at upstream gauges may be deposited along these alluvial reaches before ever reaching coast. With some of the smaller streams, the sediments may be deposited in estuaries or lagoons at the mouths of streams. Most of the major rivers, however, do not empty into estuaries but discharge into the ocean. Nevertheless, the actual sediment loads calculated and their apparent reduction may not be reflected immediately on the shoreline and sediment delivery to the coast may be considerably less than what has been calculated using stream gauge data. Sediment storage in coastal lowlands is an area of investigation that needs to be undertaken to quantify these differences and determine the actual reduction in fluvial sand delivery at the coastline.

What is clear from Table 8.4 is that bluff erosion plays an insignificant role as a source of sand for the Santa Barbara littoral cell in particular. The total amount of sand supplied to the beaches by bluff erosion, whether under natural (historical) or actual (current) conditions, is less than 1% of the total littoral budget. This is due in large part to the low percentage of sand in most of the bluff materials and the relatively low historic rates of bluff retreat. The volume of sediment supplied by the streams draining and eroding the Transverse Ranges is very large, however, although this volume has been reduced significantly by dam construction. Any plans or proposals to increase the natural sediment supply to the beaches of the Santa Barbara cell should focus on stream contributions, not the bluffs.

While streams contribute 99.5% of the littoral sand to the Santa Barbara cell, they contribute only 27.9% of the sand to the Oceanside cell. The remaining sand in the Oceanside cell comes from the erosion of the bluffs (11.6%), and from upland terrace erosion and gully enlargement (60.5%). Thus, bluff erosion is a significant contributor to this cell and future armoring proposals need to fully evaluate impacts on sand production, as is presently required by the California Coastal Commission through its *in lieu* sand mitigation fee program.

In the Santa Barbara cell, large volumes of sand are regularly dredged from the three major harbors in the cell: Santa Barbara, Ventura and Channel Islands. Because each of these harbors serves as a major littoral drift barrier, the annual or bi-annual dredging volumes should provide a reasonable indicator of long-term littoral drift rates at those points in the cell. While there are year-to-year variations in the dredging volumes, there has been no systematic reduction in the amount of sand removed each year from the harbors, strongly suggesting that there has not been a significant or regular reduction in the volume of littoral sand moving through the cell over the past 30 to 40 years. We have not collected dredging information for the Oceanside cell, so we have not assessed the issue of change in littoral sand volumes in this area.

It is recommended that a detailed study of historic beach widths and volumes within all littoral cells be carried out in order to document the extent to which a regular or systematic reduction in width has taken place, and then to determine how this reduction relates spatially and/or temporally to the reduction of natural sediment supply. Littoral drift estimates from harbor dredging rates will provide an important cross-check on any historic changes in beach width or volume. Without question, significant reductions in sand transport by the streams of both cells have taken place. Whether or not this has been reflected at the shoreline as changes in beach width, and whether the reduction has directly affected just portions of the cell or the entire cell, are issues yet to be resolved.

Selective dam removal and bypassing appear to be the approaches that have the potential to significantly increase natural sand supply and to return the littoral drift systems to their natural condition. Dams have caused the greatest reductions in the supply of sand to the coast and removal of those that are no longer serving any significant function, and bypassing of sediment around dams that are functional but impound significant volumes of sediment, should be vigorously pursued.

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8.9 GLOSSARY

Bluff: A high bank or bold headland, presenting a precipitous front; a steep cliff.

Channelized Stream: A stream whose channel has been straightened and / or deepened to permit water to flow faster.

Coastline: The general boundary between land and water, especially, the water of a sea or ocean.

Fluvial: Of or pertaining to a river; growing or living in a stream or river, produced by the action of a stream or river.

Franciscan: A complex and heterogeneous assemblage of rocks exposed in the Coast Ranges and along the sea cliffs of California consisting of sandstone, shale, conglomerate, volcanic rocks, chert and limestone as well as metamorphic rocks including serpentine.

Geographic Information System (GIS): A computer system that records, stores, and analyzes information about the features that make up the earth's surface.

Littoral Cell: A segment of coastline that includes sand sources, alongshore transport or littoral drift, and then a sink or sinks for the sand; also known as a beach compartment.

Littoral Current: A coastal current caused by waves approaching and then breaking along the shoreline at an angle. It flows parallel to and near to the shore and is also know as a longshore current.

Littoral Cutoff Diameter: Lower-end size limit for material that will be carried in the littoral drift and deposited on a particular beach. Smaller material will remain in suspension until reaching a lower-energy environment when it will fall out of suspension.

Littoral Drift: Material (such as sand, gravel, and shell fragments) that is moved along the shore by a littoral or longshore current.

Marine Terrace: A wave-cut platform that has been exposed along a coastline by uplift, a lowering of sea level, or a combination of the two.

Revetment: An engineered rock structure consisting of filter cloth, smaller core stone, and then large cap stone which is designed to armor or protect a coastal bluff, dune, or development from wave attack.

Rip-rap: A structure consisting of large rocks stacked against a bluff, dune or beach in order to provide protection from wave attack.

Runoff: That portion of precipitation that flows over the land surface as slope wash

and in stream channels.

Sea cliff: A cliff formed by wave action as well as subaerial processes.

Shoreline: The intersection of the sea or a lake with the shore or beach; it migrates with changes of the tide or of water level.

Shore-Parallel Engineering Structure: Any armor or protective structure that is constructed parallel to the coastline, such as a seawall or revetment.

Terrace: A relatively level bench or step-like surface breaking the continuity of a slope.

Uplift: A tectonic process that takes place at plate boundaries and elevates large areas of the earth's crust

Part 4

9. SUMMARY

Key findings from the California Beach Restoration Study are presented in the following sections.

The Public Beach Restoration Program

1. ***Program Funding (Fiscal Year 2000-2001):*** The state budget for fiscal year 2000-2001 included $10 million for grants to be administered by the California Department of Boating and Waterways. This expenditure represents a substantial funding increase over prior years.

2. ***Allocation of Funds:*** Funds were allocated to 16 beach projects. The majority of the program budget was used for beach nourishment, including several cost-shared projects with the Corps of Engineers. The remaining funds were used for additional studies and research into erosion control and California coastal processes (Figure 9.1).

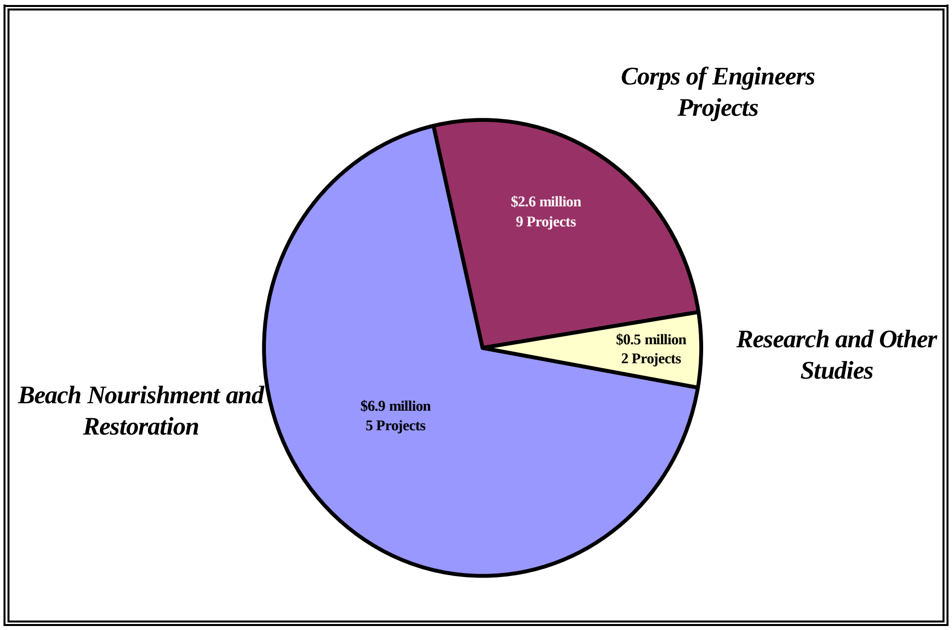

Figure 9.1. Allocation of Public Beach Restoration Program Funds (FY 2000-01)

3. *Future Needs*: The Department of Boating and Waterways has estimated that the State of California needs to invest $120 million in one-time beach nourishment costs and $27 million in annual beach maintenance costs. This investment will restore and maintain 24 miles of heavily-used beaches. Through cost-sharing partnerships with the U.S. Army Corps of Engineers, federal funding for these shoreline projects could reduce the state's costs to $42 million (65% reduction) and $13.5 million (50% reduction) for restoration and maintenance, respectively.

The Value of California's Beaches

1. ***Beach Attendance:*** Over two-thirds of Californians visit the beach each year. California's beaches experienced an estimated 659 million visitor-days in 2001, more than twice as many as the visitor-days at all U.S. National Parks combined. Of the state's top ten recreational destinations in 1991, three were beaches.

2. ***Spending on Beach Trips:*** Visitors to California beaches spent over $61 billion in 2001; approximately 36% of this total was spent by visitors from out of state.

3. ***Tax Revenues:*** California's beaches generate over $15 billion in tax revenue (excluding social insurance). Table 9.1 provides estimates for local, state, and federal tax revenue.

Table 9.1 Estimated Taxes Derived from Beach Spending

Government	Estimated Tax Generated	Percentage of Total Taxes Generated
Federal	$8.1 billion	53.4%
California State	$4.6 billion	30.5%
County	$1.2 billion	8.1%
City	$1.2 billion	8.1%
Total	**$15.2 billion**	100.0%

4. ***Value of Beach Nourishment Projects:*** Thirty-one beach nourishment projects have been evaluated for the state. Over twenty of these projects provide benefits exceeding the costs of completion. Over ten projects have benefits more than 10 times the cost of building/maintaining these projects. Failure to maintain the current infrastructure of California's beaches will lead to hundreds of millions of dollars in lost recreational and tourism revenues to the State of California.

5. ***Economic Impacts of Beach Erosion:*** Many of California's beaches are already overcrowded and, in some cases, beach erosion is making a bad situation worse. A study of north San Diego County's beaches, where erosion is a significant problem, estimated that without maintenance the state could lose $2.8 billion in direct spending and over $1 billion in taxes due to lost tourism at eroded beaches. The cost of maintaining these beaches is far less than the benefits generated. Given the current state of crowding and limited freshwater recreation activities in Southern California, most tourists would not be able to find a comparable alternative to a day at the beach.

Effectiveness of the Program

Judging by the success of prior nourishment projects conducted in California, the projects funded by the Public Beach Restoration Program offer the potential for significant improvement of the state's beaches. A brief summary of historical beach nourishment projects in California is provided below.

***Deterministic Nourishment*:** Deterministic beach nourishment projects are those that are undertaken for the primary purposes of replenishing beaches and protecting the coast. Typical motivations for such projects include mitigating the adverse effects of coastal structures and compensating for the lack of natural sediment supply from rivers and streams caused by dams and debris basins. Representative projects are:

- *Planned Regional Beach Nourishment in Orange County* - Scheduled periodic nourishment at Surfside-Sunset Beach and nourishment with sand retention devices at Newport Beach have placed nearly 18 million cubic yards of sand on northern Orange County beaches. The majority of this material has remained in the littoral system, and beach widths in the region have increased at an average rate exceeding 4 ft/yr.
- *Sand Backpassing at Peninsula Beach* - The City of Long Beach has performed sand backpassing since 1994 to alleviate chronic erosion at Peninsula Beach. Much of the program's success is due to the relatively modest construction costs, typically less than $1.50 per cubic yard.
- *Sand Bypasssing at Santa Barbara Harbor* - Sand bypassing has been conducted at Santa Barbara Harbor since 1933 to compensate for impeding the natural alongshore flow of sediment. Severe downcoast erosion was mitigated following program implementation.

***Opportunistic Nourishment*:** Opportunistic beach nourishment projects are those that are undertaken when beach-quality sand becomes available from projects unrelated to beach replenishment or coastal protection. To date, the primary sources of this "sand of opportunity" in California have been harbor construction and maintenance dredging. Opportunistic nourishment is driven by economics, in that it is often more cost effective to place the excavated material on nearby beaches than to dispose of it inland or offshore. Representative projects are:

- *Santa Monica Bay* - Over 31 million cubic yards of sand have been placed on Santa Monica Bay beaches since the 1930's. More than 90% of this material was opportunistic sand, which became available from construction and dredging activities. The cumulative effect of these independent projects was the creation of wide, sandy beaches in an area that was once sediment starved.

- *West Newport Nearshore Mound* - In 1992, 1.3 million cubic yards of beach quality sand were placed in a nearshore mound off the coast of Newport Beach. All of the material was opportunistic sand, derived from a flood control project in the nearby Santa Ana River. The shoreline advanced seaward as sand from the mound migrated landward under the influence of waves and currents.

Natural Sediment Supply

While beach nourishment is one way to increase the volume of sand on California's beaches, it is important also to consider increasing the natural supply of sediment to the shoreline. The primary source of natural sediment supply to the beach is discharge from rivers and streams. Bluff erosion is also a source of beach sand along much of the coast. Human activities have significantly affected both of these sand sources through the construction of dams, debris basins, hard channelization of stream beds, and seawalls and revetments along coastal bluffs.

In order to discuss ways to increase natural sediment supply to the coast, it is necessary to quantify the sediment volumes provided through each supply process and to assess the impact of human activities on this system.

Fluvial Sediment Supply and Reduction:

- Rivers are estimated to provide 70 to 90% of the beach-sized material to the coast.
- Over 480 major dams (under the jurisdiction of the Department of Water Resources' Division of Safety of Dams) have been built in California's coastal watersheds (excluding areas draining to San Francisco Bay).
- Coastal dams, built primarily for water supply, irrigation, and flood control, impact 38% (over 16,000 mi^2) of the state's coastal watershed area and impound 26% of the average annual beach-size sediment provided by streams.
- Southern California, from Point Conception to San Diego, is the region most highly impacted by dams, with 6 of 7 major littoral cells receiving two-thirds or less of the historical fluvial sediment supply.
- In Southern California each year, more than 1.5 million cubic yards of sand-size material are impounded behind dams and within debris basins. If sand were removed from behind just twelve dams, identified in this report, then the increase in local sand budgets would be substantial. If sand were bypassed around these dams at the same rate as long-term average sand deposition in the reservoirs created by the dams, then bypassing could offset 40% of the sediment deficit in these Southern California littoral cells.
- Material from channelized streams may constitute a significant portion of the sediment budget.

Bluff Sediment Supply and Reduction

- The great majority of the coast of California consists of actively eroding sea cliffs. More specifically, 13% of the coastline is high-relief, steep mountains that contribute a negligible amount of sand to the littoral budget, and 59% of the coastline is low-relief (less than 300 ft) wave-cut bluffs or terraces which, when eroded, will produce a greater percent of sand sized material than the high-relief, mountainous coastline.
- Approximately 102 miles of the state's coastline (10%) are presently armored; 58 miles (57%) of this armor lines coastal lowlands and dunes while the remaining 44 miles (43%) of armor protect sea cliffs.

Cell-Specific Analyses

- To assess the direct impact of human intervention on littoral sediment contributions, two littoral cells were chosen for detailed investigation. The Oceanside and Santa Barbara cells were selected for littoral cell-specific sand budget analyses, including the pre-development budget and the extent of human impact on the budgets.

Table 9.2. Sediment Inputs to the Oceanside and Santa Barbara Littoral Cells

Oceanside Littoral Cell			
Inputs	**Natural (cy/yr)**	**Actual (cy/yr)**	**Reduction in supply (cy/yr)**
Rivers	286,500 44.7%	132,500 27.9%	154,500 53.8%
Bluff Erosion	67,300 10.5%	54,900 11.6%	12,400 18.4%
Gullies/Terraces	287,000 44.8%	287,000 60.5%	0 0.0%
Total Littoral Input	640,800 100.0%	474,400 100.0%	166,400 26.0%
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Inputs	**Natural (cy/yr)**	**Actual (cy/yr)**	**Reduction in supply (cy/yr)**
Rivers	3,642,773 99.6%	2,167,000 99.5%	1,475,773 40.5%
Bluff Erosion	14,028 0.4%	11,312 0.5%	2,716 19.3%
Total Littoral Input	3,656,801 100.0%	2,178,312 100.0%	1,478,489 40.4%

Santa Barbara Cell

- Historically, streams contributed approximately 3,643,000 yds^3/yr, or 99.6% of all the sand to the Santa Barbara littoral cell. Dam construction has reduced this by 40.5% to ~2,167,000 yds^3/yr.
- Cliff and bluff erosion under natural conditions contributed only 0.4%, or ~14,000 yds^3/yr, which has been reduced 19.3% to ~11,300 yds^3/yr through the armoring of 11 miles or 14% of the bluffs in the cell.
- Human activity has reduced the overall sand supply to the Santa Barbara cell by 40.4% or 1,478,000 yds^3/yr.
- The lack of any systematic reduction in the sand dredged from the three major harbors in the Santa Barbara cell strongly suggests that there has not been a significant reduction in the volume of littoral sand moving through the cell over the past 30 to 40 years.

Oceanside Cell

- Streams in the Oceanside cell historically contributed 286,500 yds^3/yr, or 44.7%, of the naturally-supplied sand to the littoral cell. Dam construction has reduced this by 53.8% to 132,500 yds^3/yr.
- Cliff and bluff erosion under natural conditions contributed ~67,300 yds^3/yr or 10.5% of the natural littoral budget. Although the armoring of seven miles or 20% of the cliffs of the cell has reduced the sand contribution by 18.4%, the relative contribution of bluff erosion to the littoral budget has increased slightly to ~11.6% due to a greater reduction in sand supply from the streams of the cell.
- Erosion of the uplifted marine terraces and gully expansion historically and presently contribute the remaining sand in the natural sediment budget, 287,000 yds^3/yr, or 60.5% of the present littoral budget.

10. RECOMMENDATIONS

1. ***Continue Investing in Beaches:*** Past beach nourishment experience in California has shown that continued funding for sand is justified by the economic benefits from tourism and beach recreation associated with wide sandy beaches (including $4.6 billion in tax revenue for the State). Continue funding the Public Beach Restoration Program and invest in opportunistic beach replenishment.

2. ***Plan Regionally:*** The California coastal environment is diverse. As a result, beach restoration and sediment supply improvement concepts applied to one region may not be appropriate for another. Potential projects should be evaluated on a regional basis to identify the most effective solutions. The California Coastal Sediment Management Master Plan, funded through the Resources Agency, will be instrumental in enabling regional planning of sediment-related projects. As part of the Master Plan, some of the studies this report has identified as necessary to attain the goals of replenishing beaches and increasing natural sediment supply to the coast will be initiated. Identified studies include:

- *Analysis of Sediment Reduction*: A detailed study should be performed of historic beach widths and volumes to determine the extent to which any systematic reduction in beach width has taken place, and if so, how this reduction relates spatially and temporally, to the reduction in natural sediment supply.

- *Analysis of Environmental Impacts:* Environmental limits on sediment removal from individual reservoirs and debris basins should be investigated; these explorations should include grain size analysis to assess the size distributions of impounded sediments, identification of sediment transport alternatives, and assessment of impacts to estuaries due to increased fluvial sediment loads.

- *Assessment of Impacts from Increasing Sediment Transport Rates:* Fluvial systems are in quasi-equilibrium with existing sediment loads. To understand the implications of altering these loads, the geomorphological, sedimentological, and ecological impacts of increasing sand transport rates in coastal systems should be modeled.

- *Establishment of Data Collection Standards:* Better records of the number of channelized streams, miles of channelization in streams, volumes of sediment extracted from stream channels and debris basins, and the grain size distribution of the extracted sediments should be kept by local government agencies to identify opportunistic sand sources.

3. ***Remove or Bypass Dams***: Substantial increases in sand volume to local sediment budgets, resulting in wider beaches, could be realized by removing those dams that are no longer serving any useful function, and bypassing sediment around those that are functional but impound significant volumes of sand.

4. ***Promote Opportunistic Sand Nourishment:*** At a number of sites, "sand of opportunity" has been utilized as beach nourishment material with great success. However, under current guidelines, the cost and complexity of regulatory compliance often precludes the use of opportunistic material from sources such as debris basins and wetlands. The regulatory process for beach nourishment with opportunistic sand should be simplified to the maximum extent possible without compromising environmental safeguards.

5. ***Monitor Projects:*** Beach nourishment projects should be monitored to accomplish the following objectives:
   - Determine if the project meets design expectations;
   - Develop an appropriate maintenance schedule;
   - Assess environmental impacts; and
   - Quantify the economic benefits of the project.

   An increased understanding of the performance of nourishment projects in California will lead to more effective solutions to beach erosion.

Appendices

APPENDIX A. SEDIMENTATION RATE DATA FOR SELECTED DAMS

Sedimentation rate data were obtained for fourteen reservoirs/dams in Central and Southern California. The dams were selected based upon the size of the undammed drainage basin that they control (at least thirty square miles), proximity to the coast (less than thirty miles from the ocean), and the availability of data. The agency reports, from which average sedimentation rate data were derived, did not provide information on extreme events or how the sedimentation rate data were obtained.

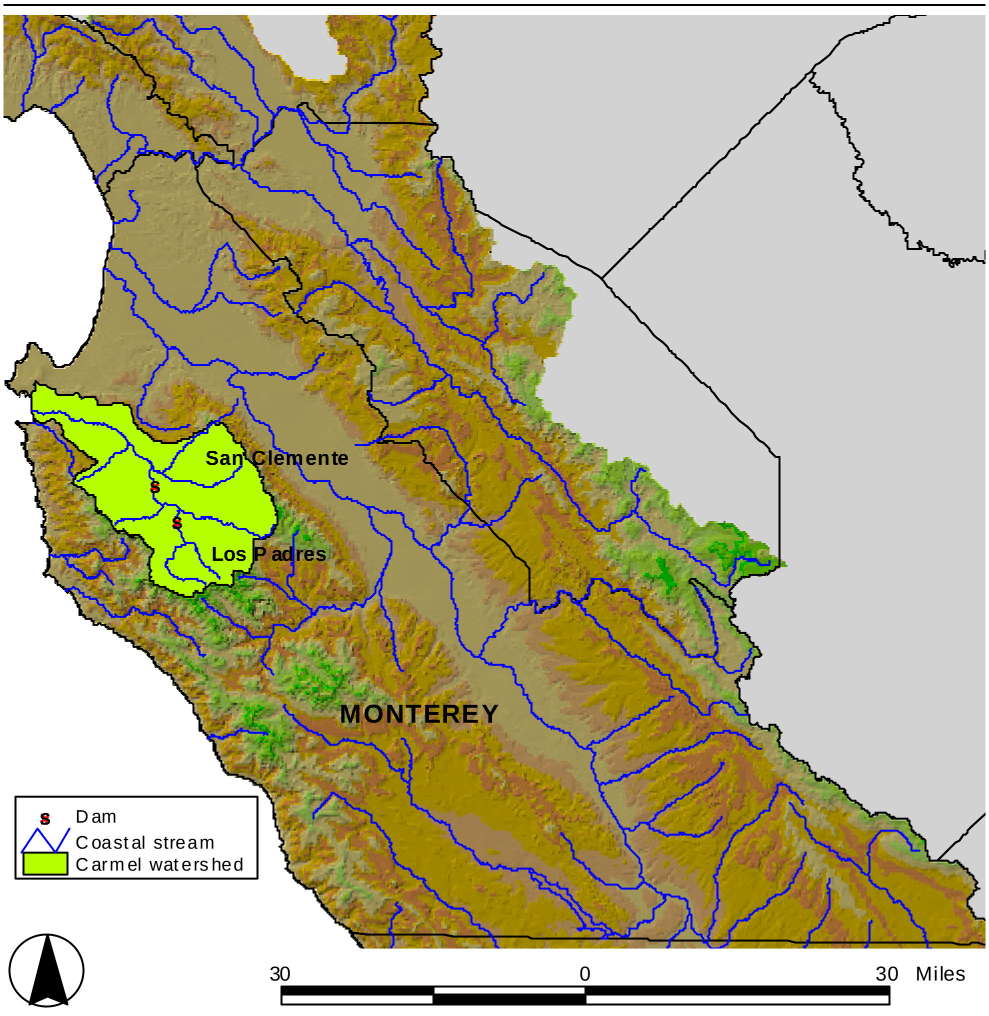

Figure A.1 Locations of Los Padres and San Clemente Dams on the Carmel River in Monterey County

Monterey County: Two dams in Monterey County are discussed: Los Padres and San Clemente (Figure A.1). The data for Los Padres Dam were provided by Mr. Andy Bell, District Engineer for the Monterey Peninsula Water Management District. Los Padres Dam is located on the Carmel River and its primary purpose is water supply. It was completed in 1949, and had an initial capacity of about 4,840,000 cubic yards. Mr. Bell estimated that capacity had been reduced to about 3,230,000 cubic yards by 2000 (original data provided in acre feet, and converted here). For those 51 years of operation, therefore, the average sedimentation rate has been about 30,000 cubic yards per year.

The data for San Clemente Dam also were provided by Mr. Bell. These data were based upon a dredging feasibility study conducted by Moffatt and Nichol in 1996. The San Clemente Dam also is located on the Carmel River, and its primary purpose is water supply. It was completed in 1921, and had an initial capacity of about 2,300,000 cubic yards. The Moffatt and Nichol study indicated that, by 1996, the reservoir's capacity had been reduced to about 240,000 cubic yards (original data provided in acre feet, and converted here). For those 75 years of operation, therefore, the average sedimentation rate has been about 30,000 cubic yards per year.

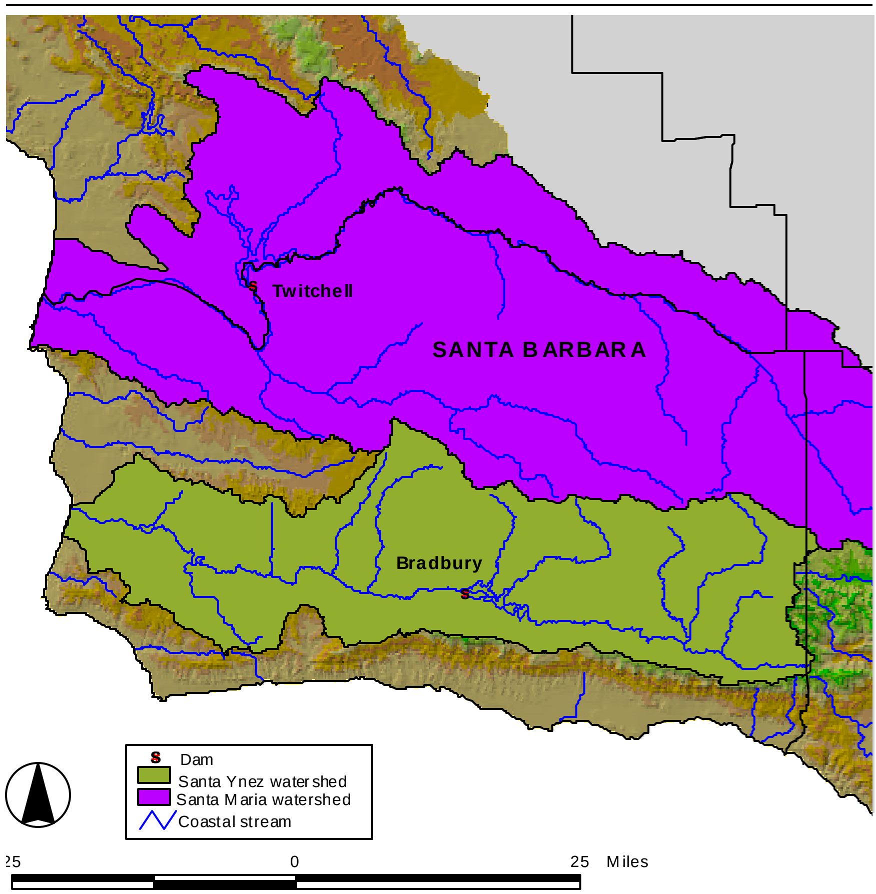

Figure A.2 Locations of Bradbury Dam on the Santa Ynez River, and Twitchell Dam on the Cuyama River in Santa Barbara County

Santa Barbara County: Two dams in Santa Barbara County are discussed: Bradbury and Twitchell (Figure A.2). The data for Bradbury Dam were provided by Mr. Robert Wignot, General Manager of the (Lake) Cachuma Operation and Maintenance Board. Bradbury Dam is located on the Santa Ynez River, and its primary purpose is water supply. It was completed in 1953, and had an initial capacity of about 330,660,000 cubic yards. A bathymetric survey of the reservoir was conducted in 2000 by MNS Engineering. The results of this survey indicated that the capacity of Lake Cachuma had been reduced to about 303,300,000 cubic yards (original data provided in acre feet, and converted here). For those 47 years of operation, therefore, the average sedimentation rate has been about 580,000 cubic yards per year.

The data for Twitchell Dam were provided by Ms. Kathleen Garnand, Civil Engineering Associate in the Santa Barbara County Water Agency, who provided a copy of the Twitchell Reservoir Sediment Management Plan, prepared in 2000 by the Santa Barbara County Water Agency with assistance from URS Greiner Woodward Clyde. Twitchell Dam is located on the Cuyama River, and its primary purposes are water supply and flood control. It was completed in 1958, and had an initial capacity of about 241,950,000 cubic yards. By 1999, the capacity of Twitchell Reservoir had been reduced to about 170,980,000 cubic yards (original data provided in acre feet, and converted here). For those 41 years of operation, therefore, the average sedimentation rate has been about 1,730,000 cubic yards per year.

Ventura County: Two dams in Ventura County are discussed: Matilija and Santa Felicia (Figure A.3).The data for Matilija Dam were provided by Mr. Charles Burton, Division Engineer in the Flood Control Agency of the County of Ventura Public Works Agency. Matilija Dam is located on Matilija Creek, and its primary purpose is water supply (Brownlie and Taylor 1981). It was completed in 1947, and had an initial capacity of about 11,270,000 cubic yards. By 1999, the reservoir capacity had been reduced to about 840,000 (original data provided in acre feet, and converted here). For those 52 years of operation, therefore, the average sedimentation rate has been about 200,000 cubic yards per year.

The data for Santa Felicia Dam were provided by Mr. James Kentosh, Manager, Operations and Maintenance Department, United Water Conservation District. The Santa Felicia Dam is located on Piru Creek, and its primary purposes are water supply and recreation (Brownlie and Taylor 1981). It was completed in 1955, and had an initial capacity of about 161,300,000 cubic yards. A bathymetric survey of the reservoir, conducted by Fugro West, indicated that, by 1996, the capacity of Lake Piru had been reduced to about 140,630,000 cubic yards (original data provided in acre feet, and converted here). For the 41 years of operation, therefore, the average sedimentation rate has been about 500,000 cubic yards per year. For the period from 1985 to 1996, however, the average sedimentation rate was only about 170,000 cubic yards per year.

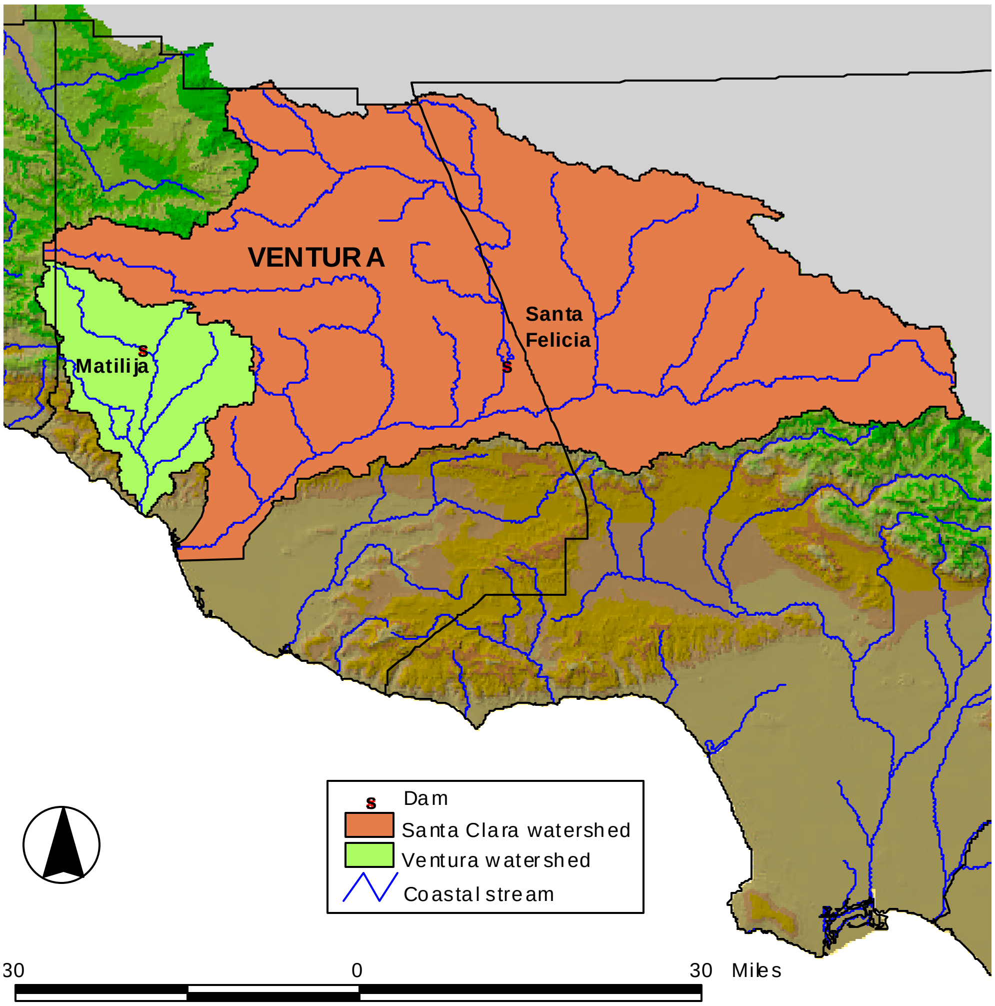

Figure A.3 Locations of Matilija Dam on Matilija Creek, and Santa Felicia Dam on Piru Creek, in Ventura County

Los Angeles County: Seven dams in Los Angeles County are discussed: Big Tujunga, Devil's Gate, Hansen, Puddingstone, San Gabriel, Santa Fe, and Sepulveda (Figure A.4). The data for Big Tujunga Flood Control Basin were obtained from a report compiled by the U.S. Interagency Advisory Committee on Water Data (Subcommittee on Sedimentation 1992). The dam is located on Big Tujunga Creek, and its primary purposes are flood control and water supply (Brownlie and Taylor 1981). It was completed in 1931, and had an initial capacity of about 10,070,000 cubic yards (original data provided in acre feet, and converted here). Average sedimentation rate data are available for fourteen intervals between 1931 and 1982. Large volumes of sediment were removed from the basin at least five times during this period. An average sedimentation rate for the 51-year period was obtained by time-weighting the average-sediment-accumulation-per-survey-interval data provided in the 1992 report. From this analysis it is estimated that, between 1931 and 1982, the average sedimentation rate was about 230,000 cubic yards per year.

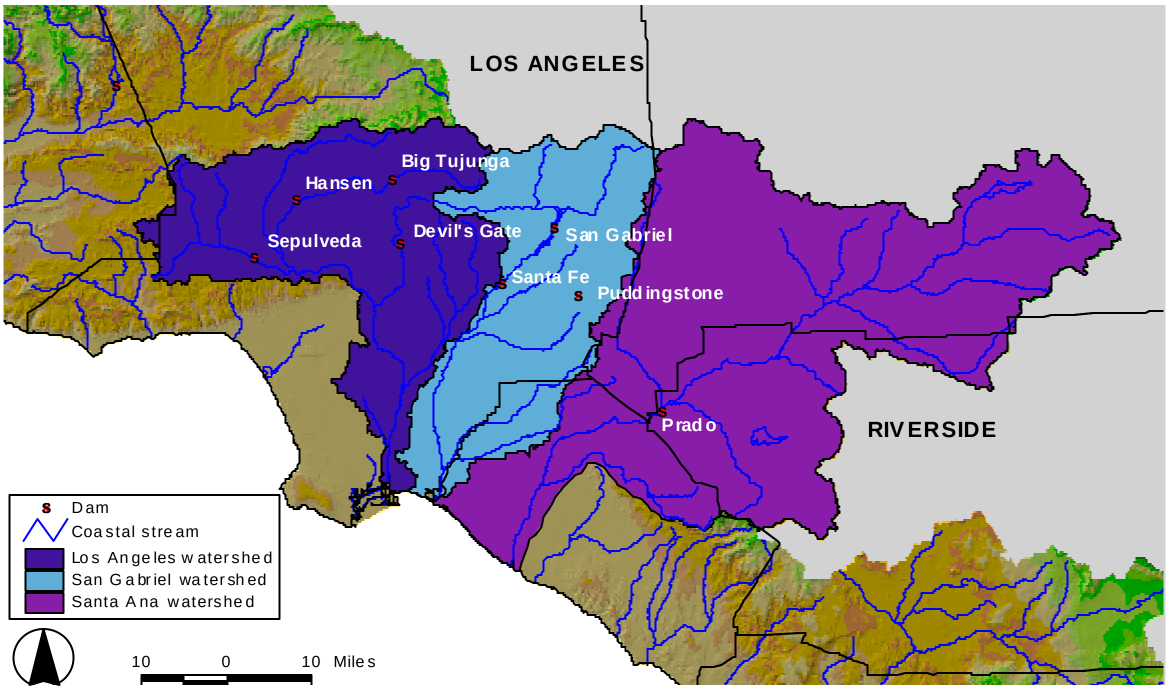

Figure A.4 Locations of Big Tujunga Dam on Big Tujunga Creek, Devil's Gate Dam on Arroyo Seco, Hansen Dam on Tujunga Wash, Puddingstone Dam on Walnut Creek, San Gabriel Dam on the San Gabriel River, Santa Fe Dam on the San Gabriel River, and Sepulveda Dam on the Los Angeles River, all in Los Angeles County, and Prado Dam on the Santa Ana River in Riverside County

The data for Devil's Gate Dam were obtained from a report compiled by the U.S. Interagency Advisory Committee on Water Data (Subcommittee on Sedimentation 1992). The dam is located on Arroyo Seco, and its primary purposes are flood control and water supply (Brownlie and Taylor 1981). It was completed in 1919, and had an original capacity of about 7,420,000 cubic yards (original data provided in acre feet, and converted here). Average sedimentation rate data are available for sixteen intervals between 1919 and 1982. Large volumes of sediment were removed from the basin at least three times during this period. An average rate for the 63-year period was obtained by time-weighting the average-sediment-accumulation-per-survey-interval data provided in the 1992 report. From this analysis, it is estimated that, between 1919 and 1982, the average sedimentation rate was about 120,000 cubic yards per year.

The data for Hansen Dam were obtained from a report compiled by the U.S. Interagency Advisory Committee on Water Data (Subcommittee on Sedimentation 1992). Hansen Dam is located on Tujunga Wash, and its primary purpose is flood control (Brownlie and Taylor 1981). It was completed in 1940, and had an original capacity of about 57,750,000 cubic yards (original data provided in acre feet, and converted here). Average sedimentation rate data are available for eight intervals between 1940 and 1983. A large volume of sediment was removed from the basin at least once during this period. An average rate for the 43-year period was obtained by time-weighting the average-sediment-accumulation-per-survey-interval data provided in the 1992 report. From this analysis, it is estimated that, between 1940 and 1983, the average sedimentation rate was about 420,000 cubic yards per year. According to Mr. Brian Tracy, Chief of the Reservoir Regulation Section of the U.S. Army Corps of Engineers Los Angeles District, there has been active sand and gravel mining from the basin. Thus, the average sedimentation rate calculated above represents a minimum value.

The data for Puddingstone Dam were obtained from a report compiled by the U.S. Interagency Advisory Committee on Water Data (Subcommittee on Sedimentation 1992). Puddingstone is located on Walnut Creek, and its primary purposes are flood control and recreation (Brownlie and Taylor 1981). It was completed in 1925, and had an original capacity of about 28,060,000 cubic yards (original data provided in acre feet, and converted here). Average sedimentation rate data are available for four intervals between 1925 and 1980. There is no indication of substantial sediment removal during this (or any other) period. An average rate for the 55-year period was obtained by time-weighting the average-sediment-accumulation-per-survey-interval data provided in the 1992 report. From this analysis, it is estimated that, between 1925 and 1980, the average sedimentation rate was about 50,000 cubic yards per year.

The data for San Gabriel Dam were obtained from a report compiled by the U.S. Interagency Advisory Committee on Water Data (Subcommittee on Sedimentation 1992). The dam is located on the San Gabriel River, and its primary purposes are flood control and water supply (Brownlie and Taylor 1981). It was completed in 1932. The reservoir had a capacity of about 86,040,000 cubic yards in 1937 (original data provided in acre feet, and converted here). Average sedimentation rate data are available for nineteen intervals between 1937 and 1983. Large volumes of sediment were removed from the basin at least five times during this period. An average rate for the 46-year period was obtained by time-weighting the average-sediment-accumulation-per-survey-interval data provided in the 1992 report. From this analysis, it is estimated that, between 1937 and 1983, the average sedimentation rate was about 770,000 cubic yards per year.

The data for Santa Fe Dam were obtained from a report compiled by the U.S. Interagency Advisory Committee on Water Data (Subcommittee on Sedimentation 1992). The dam is located on the San Gabriel River, and its primary purposes are flood control and water supply (Brownlie and Taylor 1981). It was completed in 1943. The reservoir had an initial capacity of about 55,920,000 cubic yards (original data provided in acre feet, and converted here). Average sedimentation rate data are available for six intervals between 1943 and 1982. Large volumes of sediment were removed from the basin at least once during this period. An average rate for the 39-year period was obtained by time-weighting the average-sediment-accumulation-per-survey-interval data provided in the 1992 report. From this analysis, it is estimated that, between 1943 and 1982, the average sedimentation rate was about 200,000 cubic yards per year.

The data for Sepulveda Dam were obtained from a report compiled by the U.S. Interagency Advisory Committee on Water Data (Subcommittee on Sedimentation 1992). The dam is located on the Los Angeles River, and its primary purpose is flood control (Brownlie and Taylor 1981). It was completed in 1941. The reservoir had an initial capacity of about 26,970,000 cubic yards in 1941 (original data provided in acre feet, and converted here). Average sedimentation rate data are available for two intervals between 1941 and 1980. For this 39-year period, there has been negligible sedimentation in the reservoir. Average annual sedimentation rates are trivial.

Riverside County: Prado Dam is the only Riverside County dam to be considered here (Figure A.4). The data for Prado Dam were obtained from a report compiled by the U.S. Interagency Advisory Committee on Water Data (Subcommittee on Sedimentation 1992). The dam is located on the Santa Ana River, and its primary purposes are flood control and recreation (Brownlie and Taylor 1981). It was completed in 1941. The reservoir had an initial capacity of about 359,440,000 cubic yards (original data provided in acre feet, and converted here). Average sedimentation rate data are available for three intervals between 1941 and 1979. There has been no significant sediment removal from the reservoir. An average rate for the 38-year period was obtained by time-weighting the average-sediment-accumulation-per-survey-interval data provided in the 1992 report. From this analysis, it is estimated that, between 1941 and 1979, the average sedimentation rate was about 1,130,000 cubic yards per year. Based upon data obtained in a telephone conversation with Mr. Brian Tracy, Chief of the Reservoir Regulation Section of the US Army Corps of Engineers Los Angeles District, the sedimentation rate from 1979 to 1988 was at least 1,380,000 cubic yards per year.

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APPENDIX B. DEBRIS BASIN DATA

Table B.1 Inventory of debris basins in California.

Sediment production area is uncontrolled drainage upstream of dam.

Name	Year Built	Sediment Production Area (mi^2)	Capacity (yd^3)	Total Debris Deposited (yd^3)	Debris Stored (yd^3)	Debris Removed (yd^3)	County*	Built By**`	Maintained By***
ARROYO PAREDON	1971	1.17	24000	7200	0	7200	StB	ACOE	StBCFCD
COLD SPRINGS	1964	3.67	20450	15338	0	15338	StB	ACOE	StBCFCD
FRANKLIN #14	na	na	41000	na	na	na	StB	US Soil Con Serv	StBCFCD
FRANKLIN HIGH SCHOOL #10	na	na	11600	na	na	na	StB	US Soil Con Serv	StBCFCD
FRANKLIN HIGH SCHOOL #11	na	na	12000	na	na	na	StB	US Soil Con Serv	StBCFCD
FRANKLIN MAIN	1971	0.70	12400	11160	0	11160	StB`	US Soil Con Serv	StBCFCD
FRANKLIN-MILLER	na	na	5600	na	na	na	StB	US Soil Con Serv	StBCFCD
GOBERNADOR	1971	7.03	46500	41850	0	41850	StB	ACOE	StBCFCD
LILLINGSTON CANYON CREEK	na	na	45000	na	na	na	StB	na	StBCFCD
MARIA YGNACIO EAST	1990	1.56	60000	30000	0	30000	StB	US Soil Con Serv	StBCFCD
MARIA YGNACIO MAIN	1990	3.28	30000	15000	0	15000	StB	US Soil Con Serv	StBCFCD
MISSION	1964	2.42	15000	6000	0	6000	StB	ACOE	StBCFCD
OIL CANYON	na	na	11000	na	na	na	StB	na	StBCFCD
RATTLESNAKE	1964	2.19	8300	3320	0	3320	StB	ACOE	StBCFCD
ROMERO	1971	1.72	27000	16200	0	16200	StB	ACOE	StBCFCD
SAN ANTONIO	1964	4.06	34000	20400	0	20400	StB	ACOE	StBCFCD
SAN ROQUE	1964	3.44	40000	16000	0	16000	StB	ACOE	StBCFCD
SAN YSIDRO	1964	2.66	11000	10450	0	10450	StB	ACOE	StBCFCD
SANTA MONICA DEBRIS BASIN	1977	3.28	208000	145600	0	145600	StB	US Soil Con Serv	StBCFCD
TORRO EAST	1971	0.63	15000	7500	0	7500	StB	ACOE	StBCFCD
TORRO LOWER WEST	1971	0.59	56000	28000	0	28000	StB	ACOE	StBCFCD
TORRO UPPER WEST	1971	0.94	29000	14500	0	14500	StB	ACOE	StBCFCD
ADAMS	1994	2.90	84200	67625	6120	61505	V	VCFCD	VCFCD
ARUNDELL BARRANCA (OLD)	1970	2.74	64800	326634	0	326634	V	VCFCD	VCFCD
CAVIN ROAD	1933	0.14	8700	9923	0	9923	V	VCFCD	VCFCD

Table B.1 (continued) Inventory of debris basins in California.

Sediment production area is uncontrolled drainage upstream of dam

Name	***Year Built***	***Sediment Production Area (mi^2)***	***Capacity (yd^3)***	***Total Debris Deposited (yd^3)***	***Debris Stored (yd^3)***	***Debris Removed (yd^3)***	***County****	***Built By**`***	***Maintained By******
COYOTE CANYON	1955	7.11	25300	165119	5570	159549	V	US Soil Con Serv	VCFCD
CRESTVIEW	1934	0.13	11100	0	0	0	V	VCFCD	VCFCD
DENT	1950	0.04	4100	18336	0	18336	V	VCFCD	VCFCD
EDGEMORE	1955	0.16	4000	13244	102	13142	V	US Soil Con Serv	VCFCD
ERRINGER ROAD	1957	0.16	39400	0	0	0	V	US Soil Con Serv	VCFCD
FAGAN CANYON	1994	2.90	88400	49780	6930	42850	V	VCFCD	VCFCD
FERRO	1933	0.62	37700	43690	11830	31860	V	VCFCD	VCFCD
FOX BARRANCA	1956	4.84	19300	146581	2840	143741	V	US Soil Con Serv	VCFCD
FRANKLIN BARRANCA	1934	0.52	24500	23098	23098	0	V	VCFCD	VCFCD
GABBERT CANYON	1963	3.67	49050	420929	0	420929	V	US Soil Con Serv	VCFCD
HONDA WEST	1955	1.16	14300	29655	1416	28239	V	US Soil Con Serv	VCFCD
JEPSON WASH	1961	1.34	54750	331372	35950	295422	V	VCFCD	VCFCD
LAS POSAS ESTATES (OLD)	1956	0.18	15200	14336	2816	11520	V	US Soil Con Serv	VCFCD
RAMONA (OLD)	1961	0.40	5500	12807	860	11947	V	US Soil Con Serv	VCFCD
REAL WASH	1964	0.25	31600	258136	3450	254686	V	VCFCD	VCFCD
S. BRANCH ARROYO CONEJO	1995	3.97	29750	8000	8000	0	V	VCFCD	VCFCD
SAN ANTONIO	1986	9.81	30000	74560	27360	47200	V	VCFCD	VCFCD
SANTA ROSA ROAD NO. 2	1957	1.72	15000	17201	1100	16101	V	US Soil Con Serv	VCFCD
ST. JOHNS	1957	0.38	87600	6196	0	6196	V	US Soil Con Serv	VCFCD
STEWART CANYON	1963	1.98	328300	184761	9146	175615	V	U.S. ACOE	VCFCD
TAPO HILLS NO. 2	1977	0.21	56000	10762	0	10762	V	VCFCD	VCFCD
W CAMARILLO HILLS E BRANCH	1956	0.14	4800	9312	360	8952	V	US Soil Con Serv	VCFCD
W CAMARILLO HILLS W BRANCH	1955	0.12	22500	41023	2940	38083	V	US Soil Con Serv	VCFCD
WARRING CANYON	1952	1.09	59500	339257	7000	332257	V	VCFCD	VCFCD
ALISO	1970	2.77	42000	300095	0	300095	LA	LACFCD	LACDPW

Table B.1 (continued) Inventory of debris basins in California. Sediment production area is uncontrolled drainage upstream of dam. Negative numbers for "Debris Stored" indicate "over cleaned" basins.

Name	Year Built	Sediment Production Area (mi^2)	Capacity (yd^3)	Total Debris Deposited (yd^3)	Debris Stored (yd^3)	Debris Removed (yd^3)	County*	Built By**`	Maintained By***
ARBOR DELL	1971	0.11	12000	1481	500	981	LA	CalTrans	LACDPW
AUBURN	1954	0.19	39000	104616	500	104116	LA	ACOE	LACDPW
BAILEY	1945	0.60	129000	298876	0	298876	LA	ACOE	LACDPW
BEATTY	1970	0.27	43000	15911	1800	14111	LA	LACFCD	LACDPW
BIG DALTON	1959	2.94	518000	859003	31200	827803	LA	ACOE	LACDPW
BIGBRIAR	1971	0.02	2600	4290	150	4140	LA	Dept of Parks & Rec	LACDPW
BLANCHARD	1968	0.47	75000	78771	400	78371	LA	ACOE	LACDPW
BLUE GUM	1968	0.19	40000	42759	1500	41259	LA	ACOE	LACDPW
BRACE	1971	0.29	30000	42705	900	41805	LA	Dept of Parks & Rec	LACDPW
BRACEMAR	1971	0.01	700	671	135	536	LA	Dept of Parks & Rec	LACDPW
BRADBURY	1954	0.68	90000	274161	8000	266161	LA	LACFCD	LACDPW
BRAND	1935	1.04	166000	283263	12550	270713	LA	ACOE	LACDPW
BUENA VISTA	1985	0.10	22000	690	250	440	LA	LACFCD	LACDPW
CARRIAGE HOUSE	1970	0.03	6100	7946	100	7846	LA	LACFCD	LACDPW
CARTER	1954	0.12	15000	43077	46	43031	LA	ACOE	LACDPW
CASSARA	1976	0.21	37000	29837	150	29687	LA	US Forest Service	LACDPW
CHAMBERLAIN	1974	0.04	4700	1147	-135	1282	LA	LACFCD	LACDPW
CHANDLER	1995	0.16	20000	0	0	0	LA	LACFCD	LACDPW
CHILDS	1963	0.30	50000	46518	1500	45018	LA	ACOE	LACDPW
CLOUD CREEK	1972	0.01	5100	4232	300	3932	LA	LACFCD	LACDPW
CLOUDCROFT	1973	0.21	35000	13992	3070	10922	LA	Dept of Parks & Rec	LACDPW
COOKS	1951	0.58	52000	175021	200	174821	LA	LACFCD	LACDPW
COOKS M-1A	1975	0.58	34000	na	na	na	LA	LACFCD	LACDPW
CRESTVIEW	1983	0.03	5900	50	50	0	LA	City of Duarte	LACDPW
CROCKER	1983	0.67	19000	13316	0	13316	LA	LACFCD	LACDPW

Table B.1 (continued) Inventory of debris basins in California. Sediment production area is uncontrolled drainage upstream of dam. Negative numbers for "Debris Stored" indicate "over cleaned" basins.

Name	***Year Built***	***Sediment Production Area (mi^2)***	***Capacity (yd^3)***	***Total Debris Deposited (yd^3)***	***Debris Stored (yd^3)***	***Debris Removed (yd^3)***	***County****	***Built By**`***	***Maintained By******
DEER	1954	0.59	57000	174411	2900	171511	LA	LACFCD	LACDPW
DENIVELLE	1976	0.18	7900	11355	1018	10337	LA	US Forest Service	LACDPW
DEVONWOOD	1981	0.05	11000	10215	0	10215	LA	LACFCD	LACDPW
DRY CANYON - SOUTH FORK	1978	0.49	7900	12388	0	12388	LA	LACFCD	LACDPW
DUNSMUIR	1935	0.84	103000	383128	7200	375928	LA	ACOE	LACDPW
EAGLE	1936	0.48	63000	202781	2700	200081	LA	ACOE	LACDPW
ELMWOOD	1964	0.31	61000	56661	600	56061	LA	ACOE	LACDPW
EMERALD-EAST	1964	0.32	14000	13966	3450	10516	LA	ACOE	LACDPW
ENGLEWILD	1961	0.44	41000	89050	1550	87500	LA	LACFCD	LACDPW
FAIR OAKS	1935	0.21	24000	116240	0	116240	LA	LACFCD	LACDPW
FERN	1935	0.31	43000	189652	1300	188352	LA	LACFCD	LACDPW
FIELDBROOK	1974	0.35	2800	2354	100	2254	LA	Dept of Parks & Rec	LACDPW
GOLF CLUB DRIVE	1970	0.99	15000	35243	350	34893	LA	LACFCD	LACDPW
GOOSEBERRY CREEK	1998	0.26	34000	0	0	0	LA	LACFCD	LACDPW
GORDON	1973	0.18	33000	5904	300	5604	LA	LACFCD	LACDPW
GOULD	1947	0.36	53000	122934	2050	120884	LA	LACFCD	LACDPW
GOULD UPPER	1976	0.18	52000	39178	3665	35513	LA	Dept of Parks & Rec	LACDPW
HALLS	1935	0.83	94000	613577	7400	606177	LA	LACFCD	LACDPW
HARROW	1958	0.43	68000	78498	-5360	83858	LA	LACFCD	LACDPW
HAVEN WAY	1991	0.13	34000	0	0	0	LA	Dept of Parks & Rec	LACDPW
HAY	1936	0.20	37000	75762	740	75022	LA	ACOE	LACDPW
HILLCREST	1962	0.35	58000	54649	2000	52649	LA	ACOE	LACDPW
HOG	1969	0.32	43000	11134	7200	3934	LA	LACFCD	LACDPW
HOOK EAST	1968	0.18	22000	46629	20	46609	LA	LACFCD	LACDPW
HOOK WEST	1970	0.17	22000	7488	650	6838	LA	LACFCD	LACDPW

Table B.1 (continued) Inventory of debris basins in California. Sediment production area is uncontrolled drainage upstream of dam. Negative numbers for "Debris Stored" indicate "over cleaned" basins. Negative numbers for 'Debris Removed" indicate changes in survey methods.

Name	Year Built	Sediment Production Area (mi^2)	Capacity (yd^3)	Total Debris Deposited (yd^3)	Debris Stored (yd^3)	Debris Removed (yd^3)	County*	Built By**`	Maintained By***
INVERNESS	1982	0.03	3300	498	700	-202	LA	LACFCD	LACDPW
IRVING DRIVE	1974	0.03	1200	1756	10	1746	LA	Dept of Parks & Rec	LACDPW
KINNELOA-EAST	1964	0.20	36000	112502	0	112502	LA	LACFCD	LACDPW
KINNELOA-WEST	1966	0.19	35000	151599	1250	150349	LA	LACFCD	LACDPW
LA TUNA	1955	5.34	495000	663759	11235	652524	LA	ACOE	LACDPW
LANNAN	1954	0.25	41000	103223	6600	96623	LA	US Forest Service	LACDPW
LAS FLORES	1935	0.45	56000	246554	0	246554	LA	LACFCD	LACDPW
LAS LOMAS	1983	0.07	17000	615	10	605	LA	City of Duarte	LACDPW
LIMEKILN	1963	3.72	172000	403913	0	403913	LA	US Soil Con Serv	LACDPW
LINCOLN	1935	0.50	38000	139793	2483	137310	LA	LACFCD	LACDPW
LINDA VISTA	1970	0.37	3200	14489	100	14389	LA	LACFCD	LACDPW
LITTLE DALTON	1959	3.31	661000	928373	39240	889133	LA	ACOE	LACDPW
MADDOCK	1954	0.26	45000	57134	2200	54934	LA	LACFCD	LACDPW
MARSTON/PARAGON	1988	0.20	6100	130	270	-140	LA	Dept of Parks & Rec	LACDPW
MAY NO. 1	1953	0.70	64000	223384	0	223384	LA	LACFCD	LACDPW
MAY NO. 2	1953	0.09	13000	28016	0	28016	LA	LACFCD	LACDPW
MONUMENT	1981	0.11	7000	3067	300	2767	LA	Dept of Parks & Rec	LACDPW
MORGAN	1964	0.60	79000	31091	250	30841	LA	LACFCD	LACDPW
MOUNTBATTEN	1983	0.01	1400	170	100	70	LA	Dept of Parks & Rec	LACDPW
MULL	1973	0.15	13000	2554	650	1904	LA	LACFCD	LACDPW
MULLALLY	1974	0.34	9400	70006	0	70006	LA	LACFCD	LACDPW
NICHOLS	1937	0.94	14000	131334	30	131304	LA	LACFCD	LACDPW
OAK	1975	0.05	13000	13267	0	13267	LA	US Forest Service	LACDPW
OAKGLADE	1974	0.06	7300	1657	740	917	LA	LACFCD	LACDPW
OAKMONT VIEW DRIVE	1984	0.02	3400	621	55	566	LA	Dept of Parks & Rec	LACDPW

Table B.1 (continued) Inventory of debris basins in California. Sediment production area is uncontrolled drainage upstream of dam. Negative numbers for "Debris Stored" indicate "over cleaned" basins

Name	Year Built	Sediment Production Area (mi^2)	Capacity (yd^3)	Total Debris Deposited (yd^3)	Debris Stored (yd^3)	Debris Removed (yd^3)	County*	Built By**`	Maintained By***
OLIVER	1989	0.18	32000	32980	1000	31980	LA	Dept of Parks & Rec	LACDPW
PICKENS	1935	1.50	125000	731007	1900	729107	LA	LACFCD	LACDPW
PINELAWN	1973	0.02	3200	5529	350	5179	LA	Dept of Parks & Rec	LACDPW
ROWLEY (UPPER)	1976	0.31	29000	52530	-977	53507	LA	US Forest Service	LACDPW
ROWLEY	1953	0.21	43000	79785	550	79235	LA	LACFCD	LACDPW
RUBIO	1943	1.26	150000	356373	0	356373	LA	LACFCD	LACDPW
RUBY (LOWER)	1955	0.28	29000	22732	0	22732	LA	LACFCD	LACDPW
RYE	1981	1.11	19000	17704	1200	16504	LA	Dept of Parks & Rec	LACDPW
SADDLEBACK	1988	0.04	16000	4020	1060	2960	LA	Dept of Parks & Rec	LACDPW
SANTA ANITA	1959	1.70	395000	789713	31000	758713	LA	ACOE	LACDPW
SAWPIT	1954	2.82	636000	700497	13500	686997	LA	ACOE	LACDPW
SCHOLL	1945	0.66	9300	20622	600	20022	LA	LACFCD	LACDPW
SCHOOLHOUSE	1962	0.28	68000	34490	5225	29265	LA	ACOE	LACDPW
SCHWARTZ	1976	0.25	45000	51059	1200	49859	LA	LACFCD	LACDPW
SHIELDS (UPPER)	1976	0.21	40000	45132	1900	43232	LA	US Forest Service	LACDPW
SHIELDS	1937	0.06	20000	133930	1810	132120	LA	ACOE	LACDPW
SIERRA MADRE DAM	1927	2.39	136000	391009	0	391009	LA	LACFCD	LACDPW
SIERRA MADRE VILLA	1957	1.46	402000	783502	9080	774422	LA	ACOE	LACDPW
SNOVER	1936	0.21	25000	110180	700	109480	LA	ACOE	LACDPW
SOMBRERO	1969	1.06	88000	14355	8500	5855	LA	LACFCD	LACDPW
SPINKS	1958	0.44	56000	68372	1990	66382	LA	LACFCD	LACDPW
STARFALL	1973	0.13	15000	29123	1950	27173	LA	Dept of Parks & Rec	LACDPW
STETSON	1969	0.29	41000	22052	700	21352	LA	LACFCD	LACDPW
STOUGH	1940	1.65	181000	164569	2450	162119	LA	ACOE	LACDPW
STURTEVANT	1967	0.03	1400	1426	50	1376	LA	LACFCD	LACDPW

Table B.1 (continued) Inventory of debris basins in California. Sediment production area is uncontrolled drainage upstream of dam. Negative numbers for "Debris Stored" indicate "over cleaned" basins

Name	Year Built	Sediment Production Area (mi^2)	Capacity (yd^3)	Total Debris Deposited (yd^3)	Debris Stored (yd^3)	Debris Removed (yd^3)	County*	Built By**`	Maintained By***
SULLIVAN	1970	2.38	51000	141632	0	141632	LA	LACFCD	LACDPW
SUNNYSIDE	1970	0.02	3400	4314	150	4164	LA	City of Pasadena	LACDPW
SUNSET (LOWER)	1963	0.45	159000	152630	12750	139880	LA	ACOE	LACDPW
SUNSET (UPPER)	1928	0.44	16000	149680	-1470	151150	LA	LACFCD	LACDPW
SUNSET CANYON-DEER	1982	0.21	5000	4227	250	3977	LA	LACFCD	LACDPW
TURNBULL	1952	0.99	22000	72692	400	72292	LA	LACFCD	LACDPW
VERDUGO	1935	9.40	131000	827992	13335	814657	LA	ACOE	LACDPW
WARD	1956	0.12	26000	53421	750	52671	LA	LACFCD	LACDPW
WEST RAVINE	1935	0.25	39000	172564	50	172514	LA	LACFCD	LACDPW
WESTRIDGE	1974	0.02	1400	293	280	13	LA	LACFCD	LACDPW
WILDWOOD	1967	0.65	21000	105312	0	105312	LA	LACFCD	LACDPW
WILLIAM S HART PARK	1983	0.09	2400	755	0	755	LA	LACFCD	LACDPW
WILSON	1962	2.58	313000	216133	15170	200963	LA	ACOE	LACDPW
WINERY	1968	0.18	29000	27215	0	27215	LA	ACOE	LACDPW
ZACHAU	1956	0.35	48000	111931	750	111181	LA	LACFCD	LACDPW
ALTA LOMA BASIN #3	na	na	18259	na	na	na	SB	na	SBCFCD
BADGER BASIN (E, N, S, W)	1957	na	na	na	na	na	SB	na	SBCFCD
BANANA BASIN	1944	na	na	na	na	na	SB	na	SBCFCD
BRUSH BASIN	1956	na	43261	na	na	na	SB	na	SBCFCD
CHRIS BASIN	na	na	na	na	na	na	SB	na	SBCFCD
DALEY BASIN	1953	na	53294	na	na	na	SB	na	SBCFCD
DAY CREEK #1-2	1975	na	na	na	na	na	SB	na	SBCFCD
DEMENS BASIN #1	1958	na	na	na	na	na	SB	na	SBCFCD
DEVIL BASIN #1-7	na	na	na	na	na	na	SB	na	SBCFCD
DYNAMITE BASIN	1949	na	82683	na	na	na	SB	na	SBCFCD

Table B.1 (continued) Inventory of debris basins in California. Sediment production area is uncontrolled drainage upstream of dam. Negative numbers for "Debris Stored" indicate "over cleaned" basins.

Name	Year Built	Sediment Production Area (mi^2)	Capacity (yd^3)	Total Debris Deposited (yd^3)	Debris Stored (yd^3)	Debris Removed (yd^3)	County*	Built By**`	Maintained By***
ELDER CREEK BASIN	1971	na	171462	na	na	na	SB	na	SBCFCD
HARRISON BASIN	1948	na	na	na	na	na	SB	na	SBCFCD
HILLSIDE BASIN C/E	na	na	65988	na	na	na	SB`	na	SBCFCD
LEMON BASIN	1966	na	187367	na	na	na	SB	na	SBCFCD
LITTLE SAND CANYON BASIN	1970	na	15291	na	na	na	SB	na	SBCFCD
MACQUIDDY BASIN #4	1962	na	na	na	na	na	SB	na	SBCFCD
OAK CREEK BASIN	1971	na	10097	na	na	na	SB	na	SBCFCD
PATTON BASIN	1961	na	351828	na	na	na	SB	na	SBCFCD
RICH BASIN	1955	na	237595	na	na	na	SB	na	SBCFCD
SAN ANTONIO HEIGHTS #1-6	~1920	na	44471	na	na	na	SB	na	SBCFCD
SAN SEVAINE BASIN #1-5	na	na	na	na	na	na	SB	na	SBCFCD
SAND CANYON BASIN	1971	na	14791	na	na	na	SB	na	SBCFCD
SCOTT CANYON BASIN	1975	na	47697	na	na	na	SB	na	SBCFCD
SYCAMORE BASIN	1957	na	610248	na	na	na	SB	na	SBCFCD
SWEETWATER BASIN	1955	na	na	na	na	na	SB	na	SBCFCD
WATERMAN BASIN #1-4	1940	na	na	na	na	na	SB	na	SBCFCD
WIGGINS BASIN #1	1958	na	na	na	na	na	SB	na	SBCFCD
WILSON CREEK BASIN #1-4	1959	na	na	na	na	na	SB	na	SBCFCD
MAIN STREET	1976	na	16133	na	na	17062	R	na	RCFCD

* "County" abbreviations: StB = Santa Barbara; V = Ventura; LA = Los Angeles; SB = San Bernardino; and R = Riverside.
** "Built By" abbreviations: ACOE = US Army Corps of Engineers; US Soil Con Serv = US Soil Conservation Service; VCFCD = Ventura County Flood Control District; LACFCD = Los Angeles County Flood Control District; CalTrans = California Department of Transportation; Dept of Parks and Rec = LA County Department of Parks and Recreation.
*** "Maintained By" abbreviations: StBCFCD = Santa Barbara County Flood Control District; VCFCD = Ventura County Flood Control District; LACDPW = Los Angeles County Department of Public Works; SBCFCD = San Bernardino County Flood Control District; RCFCD = Riverside County Flood Control District

APPENDIX C. STREAM CHANNELIZATION DATA

Table C.1 Summary of Stream Channelization Data

as of 8/8/01

Data Collected or Data Status	Contact	Contact Information
Del Norte County		
0 channelized streams, but some areas are armored to protect slopes	Ernie Perry	Director of Building and Planning
City of Crescent City		
No information obtained	Diane Mutchie	ccmangr@northcoast.com (no reply)
Humboldt County		
0 channelized streams, although mouth of Mad River is armored	Michael Wheeler	Planning – 707-445-7541
Mendocino County		
No information obtained	Paula Deeter	Planning Technician – 707-964-5379
City of Fort Bragg		
No information obtained		Engineering – 707-961-2823 Planning – 707-961-2827
Sonoma County		
Parts of Santa Rosa Creek are channelized… but how much Mike was unable to say	Mike Sheppard	Senior Planner – 707-543-3222

Marin County		
-Corte Madera, Nevado and Coyote Creeks contain channelized sections -Most are not hard bottom - Some dredging occurs, esp. Coyote Creek (how much and how often?) -(Beach quarrying in progress at Dillan Beach, just N. of Tomales Bay)	Tom Roberts	Engineering – 415-499-7877

San Francisco City/County		
Need Data		

San Mateo County		
No information obtained	Dave Holebrook	Sr. Planner– dholebrook@co.sanmateo.ca.us - “no time to help”
City of Daly City		
0 channelized streams	Robert Ovadia	Engineering – 650-991-8064 x8266
City of Pacifica		
No information obtained	Ken Solomon Scott Holmes	Senior Planner – 650-738-7341 Engineer – 650-738-4665 – left 2 messages
City of Half Moon Bay		
0 channelized streams	Ken Curtis	Planning Director – 650-726-8250

Santa Cruz County		
2 channelized streams – 4 miles channelized	Gary Griggs	Dir. Institute of Marine Sciences, UCSC 831-459-5006
City of Santa Cruz		
Need data		
City of Capitola		
0 channelized streams	Dave Chance	Planning – 831-475-7300
City of Marina		
No information obtained	Jim Felton	Senior Planner - 831-884-1220
City of Sand City		
No information obtained	Steve Matarazzo	Planning - 831-394-6700-x13

Monterey County / City		
No data	Ramon Montano	831-755-5139 (left message)

San Luis Obispo County		
No information obtained	Matt Jansen	Planning Supervisor – 805-781-5104
City of San Luis Obispo		
No information obtained	Matt Jansen	Planning Supervisor – 805-781-5104
City of Pismo Beach		
0 channelized streams	Carolyn Johnson	Planner – 805-773-4659
City of Grover City		
0 channelized streams	Susan Clark	Receptionist – 805-473-4520

Santa Barbara County		
No data on file – although sediment has been removed	Neil Cole	Principal Engineer – ncole@COSB.org

from Stevens Creek over the last 3 years –the quantities are not on file b/c it was done on a lump sum basis.		
City of Santa Barbara		
-Mission Creek: ¾mile long trapezoidal channel -San Pedro and San Jose Creeks may be partially channelized --7 streams drain into the Goleta slough; sediment is removed from the sediment basins and taken to Goleta Beach, then deposited offshore into the littoral cell. How much is not well known.	Janice Hubble Brian Baca	Development Review Supervisor – 805-564-5470 County geologist – 805-568-2000 (Attempted to contact. No reply)
City of Carpinteria		
No data	Tom Evans David Durflinger	Engineer – 805-692-6921 (left messages. no reply) Head of Community Development. – 805-684-5405 x414 (left messages. no reply)

Ventura County		
"Some of the smaller channels are concrete and they are excavated every few years" 159,750 total m^3 removed in 1978 channel cleanouts: 460 m^3 from Ventura River Channels 136,750 m^3 from Santa Clara River Channels 22,540 m^3 from Callegas Creek	Kevin Keivanfar Kolker, 1982	Flood Control - 805-654-2906

City of Buenaventura		
Barrancas (sp?) Channelized Streams – controlled by Ventura County Flood Control	Albert Carbon	Engineering – 805 - 654-7887
City of Oxnard		
No data	Juan Martinez	Planning - 805-385-7858 (no reply)
City of Port Hueneme		
- Bubbling Springs corridor is partially channelized -'J' Street canal - operated by Ventura County - concrete bed.	Greg Brown	Community Development Director - 805-986-6553

Los Angeles County		
-460 miles of channels maintained by the Department of Water. - Fiscal Year 1998-99: 13,190 tons of sediment removed - Fiscal Year 1999-00: 43,809 tons of sediment removed - Material gets removed in the summer months to prepare for winter	Jerry Burke	LADW – Flood Maintenance Division (jburke@dpw.co.la.ca.us) (626-458-4114)
City of Los Angeles		
No data		
City of Santa Monica		
No data	Dave Britain	Snr Civil Engineer– 310-458-2205 (left message)
City of Manhattan Beach		
0 % channelized streams	Richard Thompson	Planning – 310-545-5621
City of Redondo Beach		

0% channelized streams	Tom Baldwin	Engineering – 310-318-0661
City of Palos Verdes Estates		
No channelized streams (but retention basins – maintained by LA County are present)	Wendy Force	Public Works – 310-378-0383
City of Rancho Palos Verdes		
- Segments of a few streams are armored: ~ 5% of total - No excavation of sediment occurs	Dean Allison	Dir. of Public Works – deana@rpv.com - 310-544-5252
City of Long Beach		
No data		

Orange County		
*From July 1972 thru 1977: 1. San Gabriel River (including Coyote Creek, Carbon Creek and Los Alamitos Channel) had 137,480 cubic meters removed for sale. 2. Huntington Beach Group (including Bolsa Chica Channel and East Garden Grove-Wintersburg Channel) had 65,400 cubic meters removed for sale. 3. Santa Ana River Group (including Greenville-Banning Channel) had 444,800 cubic meters removed for sale. 4. Laguna Hills Group (total) 276,500 cubic meters removed for sale [195,200 from San Diego Creek; 81,300 from San Juan Creek]. 5. Grand Total: 924,180 cubic meters removed for sale	Kolker, 1982	

City of Seal Beach		
No channelized streams in Seal Beach	Karen Walton	Pubic Works – 562-431-2527
City of Huntington Beach		
- Huntington Beach does not maintain any channels that drain into the ocean; the County of Orange controls all those channels. Huntington does maintain storm drain channels (5) total length unknown	Steve Krieger	Engineering – 714-536-5431
-Storm Channels get excavated, but this material was originally beach sand that has drifted up into the storm drainage channel and plugged it. This material is just bulldozed onto the beach. -Silt and Sand is removed from San Diego Creek prior to entering Newport Bay --- The Irvine Water District is now in charge of this silt & sand removal with a goal of preventing all silt / sand to getting into Newport Bay. Recently, a nine month, ~$25 million dredging program just moved ___?___ cu. yds of material into the ocean from the bay. -About 4 miles [estimated off the top of his head] of the Santa Ana River is Hard Bottom (concrete): (btw Golden Grove and Adams freeway)	Rick Schooley	Maintenance – 714-567-6230
City of Newport Beach		
No data	Greg Ramirez	Planning – 949-644-3225 x3219
City of Laguna Beach		
No data	Scott Drampkin	949-497-0713 (no reply)

City of San Clemente		
- Some streams are channelized, how many? - Sediment is not removed from streams on any regular basis	Tom Bonigut	Snr Civil Engineer – 949-361-6187 BonigutT@san-clemente.org

San Diego County		
Left Message – no reply yet	Kent Burnham	Flood Control – 858-874-4084
City of Oceanside		
No data	Greg Mayer	760-966-4752 gmayer@ci.oceanside.ca.us (Emailed. No reply)
City of Carlsbad		
-No channelized streams in Carlsbad with the exception of structural sections such as areas that go underneath overpasses, etc. (much less than ¼ mi. total) -No excavation takes place.	Rosanna Lacarra	Environmental Programs Manager - 760-602-2720 (left message – no reply)
City of Encinitas		
-Streams are cleaned, washed and vacuumed and sediment goes to a landfill if hazardous, or to construction if not. - Fish and Game is responsible for excavating material out of channels and this has been ongoing only since about October, 2000. They have so far removed 40 cu yds of material (debris, trash and sand).	Frank McDermitt	Flood Control - 760-633-2652
City of Solana Beach		
- Stevens Creek, the only stream in town, is partially channelized (soft and hard channel). - Material is excavated on a regular basis (once / year	Neil Coral	Engineer – 858-720-2474

around Sept. or Oct) - Material goes into landfills when hazardous, otherwise used to enhance city fairgrounds		
City of Del Mar		
-1 drainage channel for city run off -- but no channelized streams	Bob Scott	Public Works – 858-755-9313 (Very willing to help!)
City of San Diego		
No data	Linda Lugano	619-236-5555 (left message - no reply)
City of Coronado		
No channelized streams	Marnell Gibson	Public Works – 619-522-7800
City of Imperial Beach		
No data		

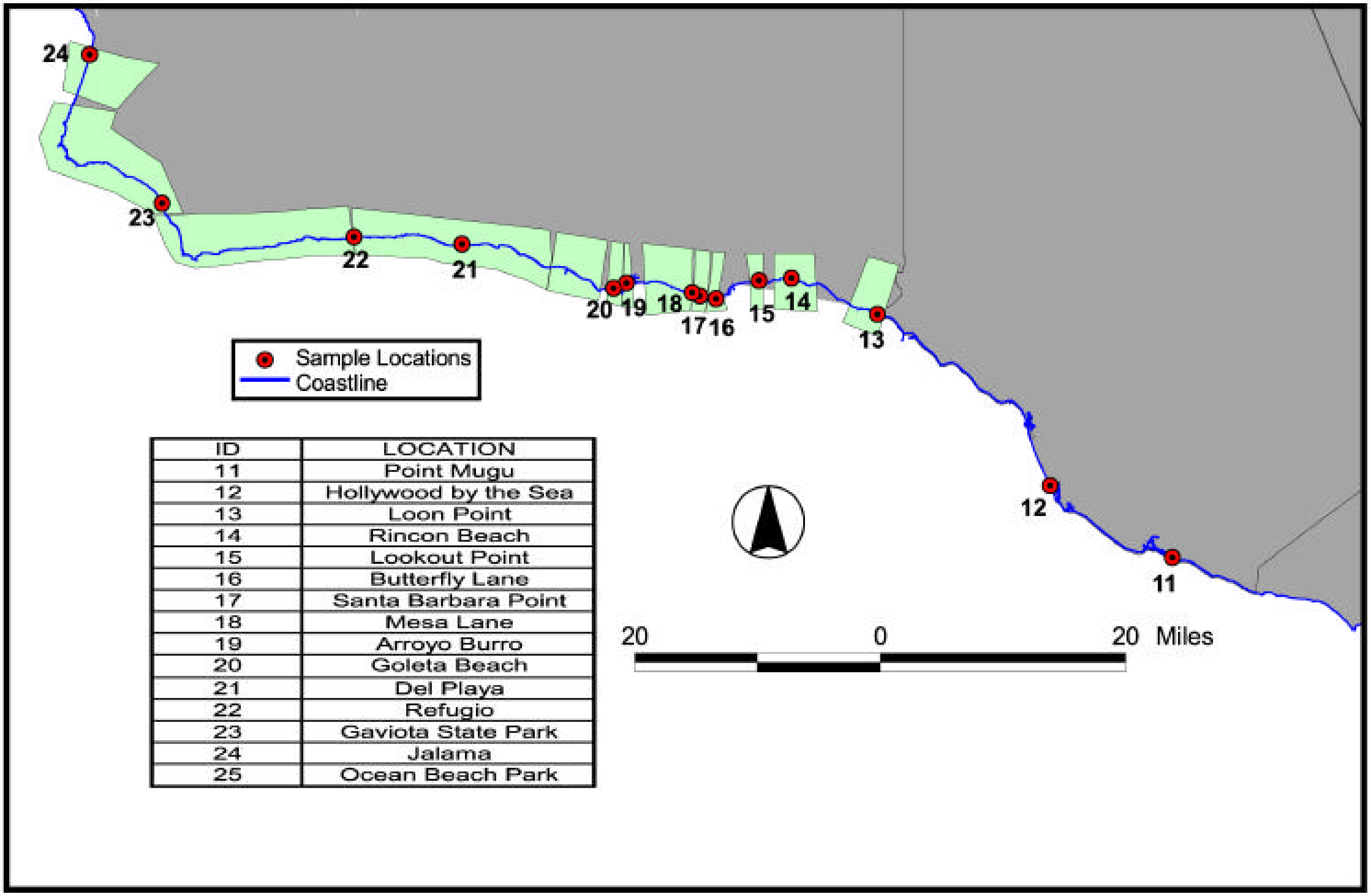
APPENDIX D. BLUFF CONTRIBUTION DATA

Table D.1 Field Data From the Santa Barbara Littoral Cell.

SAMPLE#	GPS WAYPT	LOCATION	TIME	DATE	LAT	LONG	B-C-T	CLIFF HEIGHT	SITE LENGTH	TERRACE THICKNESS	SCHMITT HAMMER
1	4	Pt. Mugu	17:00	4/26/2001	34 05.195	119 03.739	Beach				
2	5	Hollywood by the Sea	17:25	4/26/2001	34 10.387	119 14.131	Beach				
3	6	Rincon Point- Loon Point	18:00	4/26/2001	34 22.606	119 28.831	Cliff	30	5540	0.5	10
4	7	(sample Rincon Beach)			34 22.602	119 28.844	Beach				
5							Terrace				
6	8	Loon Point to Fernald Point	9:00	4/27/2001	34' 25.183	119' 36.158	Beach	21	2934	1-1.5	
7		(sample Lookout Pt)					Cliff				18
7a							Cliff				16
8							Terrace				
9	9	Fernald Point to SB Cemetary	10:00	4/27/2001	34' 25.039	119' 38.930	Beach	29	1350		
10		(sample end of Butterfly Lane)					Cliff/terrace				10
11	10	SB Point to Lighthouse	11:00	4/27/2001	34' 28.785	119' 42.365	Beach	14	2080	3	22
12							Cliff				
13							Terrace				
14	11	Lighthouse to Arroyo Burro	12:00	4/27/2001	34' 23.758	119' 42.622	Beach	14.3	1995	4	42
15		(sample Mesa Lane Stairs)					Cliff				
16	13	Arroyo Burro to Hope Ranch	13:00	4/27/2001	34' 24.191	119' 44.687	Beach	13.7	4200	0.5	14
17							Cliff				
no access:		Hope Ranch- Goleta Pier					No access:				
18	14	Goleta Beach to Goleta Point	13:40	4/27/2001	34' 24.890	119' 50.271	Beach	6.5	1600	3 to 4	28
19		(sample Goleta Beach)					Cliff				
20							Terrace				
21	15	Goleta Point to Coal Oil Point	14:45	4/27/2001	34' 24.521	119' 51.361	Beach	10.2	1960	4	21
22		(sample Del Playa)					Cliff				
23							Terrace				
no access:		Coal Oil Point to Naples	*(use data from next site)				No access:		7280		
24	16	Naples to Port Orford (Gaviota St. Beach)	15:55	4/27/2001	34' 27.651	120' 04.401	Beach	10.2	23640	1	10-20 and 45-55
25		(sample Refugio)					Cliff				
26							Terrace				
27	17	Port Orford to Jalama	16:35	4/27/2001	34' 28.733	120' 13.733	Beach	6.5	28331	0	40
28		(sample Gaviota State Park)					Cliff				
29	18	Jalama to Spring Canyon	18:15	4/27/2001	34' 30.468	120' 30.052	Beach	7.6	31596	2	31
30							Cliff				
31							Terrace				
32	19	Mouth of Santa Ynez River	19:15	4/27/2001	34' 40.977	120; 36.389	DUNE				
		Ocean Beach Park									

Table D.2 Field Data From the Oceanside Littoral Cell.

SAMPLE#	GPS WAYPT	LOCATION	LAT	LONG	B-C-T	CLIFF HEIGHT (M)	SITE LENGTH (M)	TERRACE THICKNESS (M)	SCHMITT HAMMER
100	21	La Jolla Shores	32 51.288	117 15.561	Beach				
101	22	Scripps Pier	32 52.049	117 15.235	Beach	28	6832	3.4	26.4
102					Cliff				
103					Terrace				
104					Cliff2				
105	23	Torrey Pines	32 51.279	117 15.539	Beach	7.7	2556	3.4	12
106					Cliff				
107					Terrace				
108		Power House Park			Beach	8	2858	3.9	20
109					Cliff				
110					Terrace				
111	24	Fletcher	32 57.628	117 16.032	Cliff	4.6	1346	6.2	24
112	25	Encinitas	33 02.078	117 17.561	Beach	14.1	1179	2.8	18
113					Cliff				
114	26	Cardfif	33 01.619	117 17.265	Cliff	9.9	3858	3.7	18
115					Beach				
117	27	Beacon	33 03.983	117 18.353	Beach	3.1	8047	4.3	16
118					Cliff				
119					Terrace				
120	28	San Onofre	33 22.448	117 33.965	Cliff	7.3	19680	0.5	10
121					Beach				
122	29	San Clemente	33 25.819	117 37.847	Beach	13.2	5767	2.3	12
123					Cliff				



ID	LOCATION
11	Point Mugu
12	Hollywood by the Sea
13	Loon Point
14	Rincon Beach
15	Lookout Point
16	Butterfly Lane
17	Santa Barbara Point
18	Mesa Lane
19	Arroyo Burro
20	Goleta Beach
21	Del Playa
22	Refugio
23	Gaviota State Park
24	Jalama
25	Ocean Beach Park

Figure D.1 Sample Locations for the Santa Barbara Littoral Cell

Table D.3 Grain Size Analysis to Determine Littoral Cell Cutoff Diameter in San Diego

LOCATION	PHI	RAW WEIGHT	CUM. WEIGHT	INDIVIDUAL %	CUM. %
La Jolla Shores	1	0.77	0.77	0.44%	0.44%
#100	1.5	1.12	1.89	0.64%	1.09%
Beach	2	13.28	15.17	7.63%	8.71%
	2.5	83.55	98.72	47.98%	56.69%
	3	59.75	158.47	34.31%	91.00%
	3.5	14.79	173.26	8.49%	99.49%
	>3.5	0.88	174.14	0.51%	100.00%
N. Scripps Pier	1	0.92	0.92	0.64%	0.64%
#102	1.5	0.84	1.76	0.58%	1.22%
Beach	2	7.03	8.79	4.88%	6.10%
	2.5	65.88	74.67	45.75%	51.85%
	3	54.44	129.11	37.80%	89.65%
	3.5	14.25	143.36	9.90%	99.55%
	>3.5	0.65	144.01	0.45%	100.00%
Torrey Pines	1	2.69	2.69	1.05%	1.05%
#105	1.5	10.22	12.91	3.97%	5.02%
Beach	2	96.27	109.18	37.42%	42.44%
	2.5	104.63	213.81	40.67%	83.12%
	3	37.08	250.89	14.41%	97.53%
	3.5	5.96	256.85	2.32%	99.85%
	>3.5	0.39	257.24	0.15%	100.00%
Power House Park	1	4.48	4.48	1.98%	1.98%
#108	1.5	12.28	16.76	5.42%	7.40%
Beach	2	85.52	102.28	37.76%	45.16%
	2.5	90.19	192.47	39.83%	84.99%
	3	28.46	220.93	12.57%	97.56%
	3.5	5.14	226.07	2.27%	99.83%
	>3.5	0.39	226.46	0.17%	100.00%
Encinitas Swami	1	0.94	0.94	0.97%	0.97%
#112	1.5	0.91	1.85	0.93%	1.90%
Beach	2	7.19	9.04	7.39%	9.29%
	2.5	44.64	53.68	45.86%	55.14%
	3	43.41	97.09	44.59%	99.73%
	3.5	0.26	97.35	0.27%	100.00%
	>3.5	0	97.35	0.00%	100.00%

Cardiff	1	1.3	1.3	0.90%	0.90%
#115	1.5	3.5	4.8	2.42%	3.31%
Beach	2	23.21	28.01	16.03%	19.34%
	2.5	69.63	97.64	48.08%	67.42%
	3	39.19	136.83	27.06%	94.48%
	3.5	7.69	144.52	5.31%	99.79%
	>3.5	0.31	144.83	0.21%	100.00%
Beacon	1	1.57	1.57	0.55%	0.55%
#117	1.5	5.36	6.93	1.88%	2.43%
Beach	2	148.57	155.5	52.17%	54.60%
	2.5	97.17	252.67	34.12%	88.72%
	3	28.24	280.91	9.92%	98.64%
	3.5	3.84	284.75	1.35%	99.99%
	>3.5	0.04	284.79	0.01%	100.00%
San Onofre Beach	1	178.7	178.7	50.15%	50.15%
#121	1.5	89.3	268	25.06%	75.21%
Beach	2	74.22	342.22	20.83%	96.04%
	2.5	12.22	354.44	3.43%	99.47%
	3	1.6	356.04	0.45%	99.92%
	3.5	0.2	356.24	0.06%	99.97%
	>3.5	0.1	356.34	0.03%	100.00%
San Clemente	1	201.1	201.1	60.31%	60.31%
#122	1.5	75.52	276.62	22.65%	82.95%
Beach	2	42.42	319.04	12.72%	95.67%
	2.5	10.8	329.84	3.24%	98.91%
	3	2.62	332.46	0.79%	99.70%
	3.5	0.92	333.38	0.28%	99.97%
	>3.5	0.09	333.47	0.03%	100.00%

Table D.4 Grain Size Analysis to Determine Littoral Cell Cutoff Diameter in Santa Barbara

LOCATION	PHI	RAW WEIGHT	CUM. WEIGHT	INDIVIDUAL %	CUM. %
Pt. Mugu (#1)	1	51.2	51.2	37.90%	37.90%
	1.5	46.3	97.5	34.28%	72.18%
	2	31.7	129.2	23.47%	95.65%
	2.5	5.1	134.3	3.78%	99.42%
	3	0.7	135	0.52%	99.94%

	3.5	0.07	135.07	0.05%	99.99%
	>3.5	0.01	135.08	0.01%	100.00%
Santa Barb	1	9.94	9.94	4.92%	4.92%
Point (#11)	1.5	22.44	32.38	11.11%	16.04%
	2	86.58	118.96	42.88%	58.91%
	2.5	67.78	186.74	33.57%	92.48%
	3	14.15	200.89	7.01%	99.48%
	3.5	0.99	201.88	0.49%	99.98%
	>3.5	0.05	201.93	0.02%	100.00%
Del Playa	1	3.61	3.61	1.44%	1.44%
#21	1.5	20.01	23.62	7.97%	9.41%
	2	138.56	162.18	55.22%	64.63%
	2.5	68.51	230.69	27.30%	91.93%
	3	19.06	249.75	7.60%	99.53%
	3.5	1.14	250.89	0.45%	99.98%
	>3.5	0.05	250.94	0.02%	100.00%
Refugio	1	9.06	9.06	4.09%	4.09%
#24	1.5	20.98	30.04	9.48%	13.57%
	2	110.22	140.26	49.79%	63.36%
	2.5	59.39	199.65	26.83%	90.19%
	3	18.64	218.29	8.42%	98.61%
	3.5	3.06	221.35	1.38%	99.99%
	>3.5	0.015	221.365	0.01%	100.00%
Jalama	1	5.55	5.55	6.72%	6.72%
#29	1.5	12.89	18.44	15.60%	22.32%
	2	34.41	52.85	41.65%	63.98%
	2.5	26.79	79.64	32.43%	96.40%
	3	2.87	82.51	3.47%	99.88%
	3.5	0.07	82.58	0.08%	99.96%
	>3.5	0.03	82.61	0.04%	100.00%
Ocean Beach Park	1	4.4	4.4	1.62%	1.62%
	1.5	48.15	52.55	17.68%	19.29%
	2	176.02	228.57	64.62%	83.91%

	2.5	39.93	268.5	14.66%	98.57%
	3	3.73	272.23	1.37%	99.94%
	3.5	0.11	272.34	0.04%	99.98%
	>3.5	0.06	272.4	0.02%	100.00%

Table D.5 Grain Size Analysis of Sea Cliff Samples from Santa Barbara

Santa Barbara		Original weight (g)		Post tumble (4 phi screen)			Finer than 3.0 phi (g)	Cliff/terrace that will end up on the beach (g)	% of sand size material emanating from cliff
	Beach/cliff	Beach	Cliff/terrace	Total (g)	Cliff only remaining (g)	Pebbles (g)			
Santa Barbara Point	Cliff	100	100	121	21	0.05	4.7	16.25	16.26%
Del Playa	Cliff	100	78.4	100.1	0.1	1.4	0.9	-2.2	-2.86%
Del Playa	Terrace	100	100	140.9	40.9	9.42	29.54	1.94	2.14%
Mesa Lane	Cliff	100	99.8	128.5	28.5	30.6	4.63	-6.73	-9.73%
Arroyo Burro	Cliff	100	100	128.6	28.6	21.1	2	5.5	5.50%
Refugio	Cliff	100	100	181.7	81.7	84.2	3.7	-6.2	-6.20%
Jalama	Cliff	50	50	90.8	40.8	41.7	1.3	-2.2	-4.40%
Rincon Point	Cliff	100	100	109.2	9.2	8.4	2.7	-1.9	-1.90%
Goleta Beach	Cliff	100	100	119.2	19.2	19.4	3	-3.2	-3.20%
Gaviota Beach	Cliff	50	50	88	38	42.4	3.1	-7.5	-15.00%
Samples that did not get tumbled									
Refugio	Terrace	0	100	99.8	99.8	6.1	12.6	81.1	81.10%
Jalama	Terrace	0	50	49.5	49.5	6.9	10.2	32.4	64.80%
Goleta Beach	Terrace	0	100	99.5	99.5	8.7	46.2	44.6	44.60%
Butterfly Lane	Terrace	0	100	100.1	100.1	2.6	26.5	71	71.00%
Rincon Point	Terrace	0	100	99.8	99.8	14.8	15.3	69.7	69.70%

Table D.6 Grain Size Analysis of Sea Cliff Samples from San Diego

San Diego		Original Weight (g)		Post Tumble (4 phi screen)			Finer than 3.0 phi (g)	Cliff/Terrace that will end up on the beach (g)	% of sand size material emanating from cliff beach
	Beach/Cliff	Beach	Cliff/Terrace	Total (g)	Cliff only remaining (g)	Pebbles (g)			
San Onofre	Cliff	100	100	160.1	60.1	1.84	3.8	54.46	55.48%
Torrey Pines	Cliff	100	100	156.1	56.1	2.36	5.5	48.24	49.41%
Torrey Pines	Terrace	100	100	160.3	60.3	5.45	4	50.85	53.78%
Cardiff	Cliff	50	50	76.1	26.1	0.44	3.5	22.16	44.71%
Cardiff	Terrace	50	50	84.1	34.1	0	0.7	33.4	66.80%
N. Scripps Pier	Terrace	50	50	64.5	14.5	5.1	7.1	2.3	4.60%
Encinitas (Swamis)	Cliff	100	100	181.2	81.2	4.4	5.5	71.3	71.30%
San Clemente	Cliff	100	100	111.1	11.1	5.9	6.8	-1.6	-1.60%
Powerhouse Park	Cliff	100	100	167.7	67.7	4.4	17.3	46	46.00%
Powerhouse Park	Terrace	100	100	186.9	86.9	0	1.7	85.2	85.20%
Beacon	Terrace	100	100	192.3	92.3	0	0.3	92	92.00%
Beacon	Cliff	100	100	180.3	80.3	8.9	6.4	65	65.00%
N. Scripps Pier	Terrace	50	50	99.8	49.8	13.6	10.4	25.8	51.60%

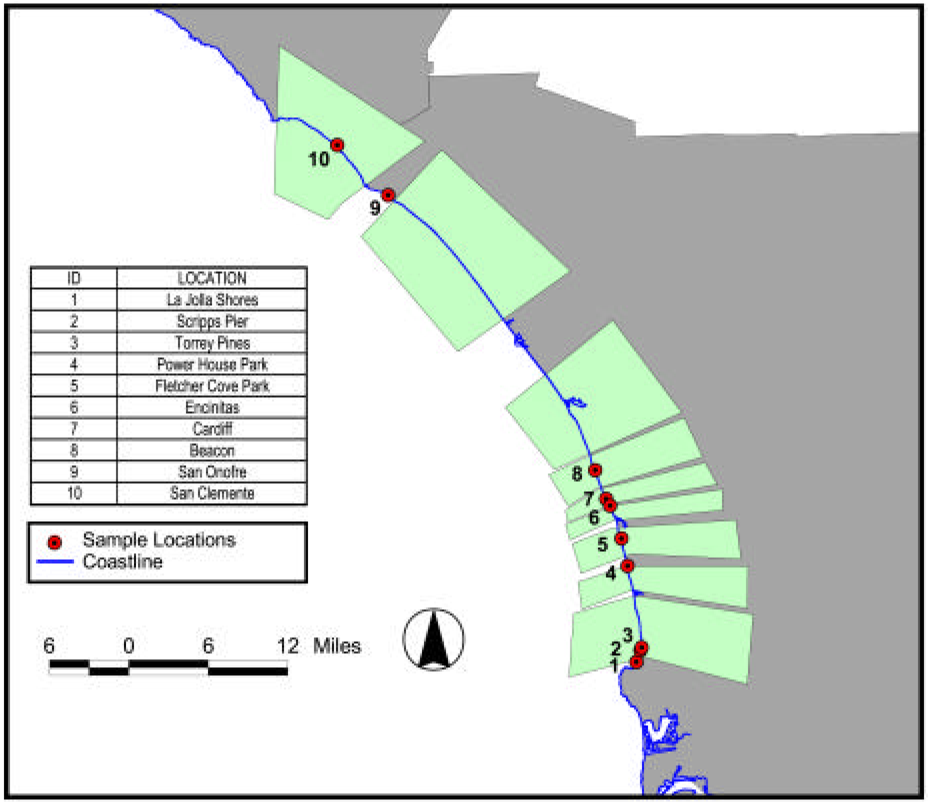


Figure D.2 Sample sites in the Oceanside Littoral Cell

Table D.7 California Coastal Armor Summary: 1971 to 2001

CALIFORNIA COASTAL ARMOR SUMMARY: 1971 TO 2001 All data shown in kilometers								
Location	**Total Shoreline[1]**	**1971 Armor[2]**	**1977 Armor[3]**	**1989 Armor[4]**	**1998 Armor[5]**	**2001 Armor[6]**	**Breakwaters[7]**	**Total**
	(km)	**(km)**	**(km)**	**(km)**	**(km)**	**(km)**	**(km)**	**(km)**
Del Norte County	73.06	1.93	1.00	7.24		0.92	2.09	3.01
City of Crescent City	4.02			2.01		no data		
Humboldt County	195.70	0	0.00	0.06		0.98		0.98
Mendocino County	196.66	0	0.31	0.48		no data	0.48	0.48
City of Fort Bragg	5.63			0.00		no data		
Sonoma County	100.58	[0.32]	0.00	0.06	0.02	1.69	0.00	1.69
Marin County	112.98	2.74	1.29	1.61	2.25	no data		2.25
San Fransisco City / County	13.52	1.93	2.03	3.22	2.25	-		2.25
San Mateo County	89.96	0	2.72	0.31		5.50	2.41	7.91
City of Daly City	4.18			0.21		0.61		
City of Pacifica	9.66			4.02		no data		
City of Half Moon Bay	9.98		0.00	-		0.21		
Santa Cruz County	67.27	4.67 (+prvt SWs)	6.18	16.09	12.87		0.00	12.87
City of Sant Cruz	9.66			0.80				
City of Capitola	2.25			1.29		0.61		
Monterey County	179.12	0	3.03	1.61	1.45	5.92	1.00	6.92
City of Marina	5.31			0.00		no data		
City of Sand City	2.41			0.48		no data		
City of Monterey	5.63			1.61		no data		
San Luis Obispo County	148.54	0.48 & [2.25]	4.43	4.02	0.97	4.20	2.55	6.75
Pismo Beach	11.27			1.61		3.22		
Santa Barbara County	176.71	5.63 & [0.80]	14.08	16.09	22.53	no data	0.80	23.33
City of Santa Barbara	9.66			2.41		0.55		
City of Carpinteria	4.02			0.00		no data		

Ventura County	66.31	18.02 & [1.77]	26.23	43.45	30.09	no data	1.10	31.19
City of Buenaventura	10.46			2.41		no data		
City of Oxnard	10.46			0.08		no data		
City of Port Hueneme	2.41			1.21		0.48		
Los Angeles County	118.77	3.21 & [2.90]	8.05	4.02		1.67	16.74	18.41
City of Los Angeles	25.75			7.24 (bw - not in total)		no data		
City of Santa Monica	4.83			0.00		0.00		
City of Manhattan Beach	3.62			0.14		0.14		
City of Redondo Beach	4.02			1.61		no data		
City of Palos Verdes Estates	8.85			0.14		0.16		
City of Rancho Palos Verdes	12.07			0.24		0.24		
City of Long Beach	8.05			7.56		no data		
Orange County	67.43	0.32 & [2.74]	20.62	3.22	19.63	no data	1.93	21.56
City of Seal Beach	4.02			3.22		no data		
City of Huntington Beach	13.68			1.61		no data		
City of Newport Beach	8.45			1.61		no data		
City of Laguna Beach	10.46			3.22		no data		
City of San Clemente	7.32			7.32		no data		
San Diego County	122.47	5.79 & [3.54]	10.06		38.30	0.00	1.11	39.41
City of Oceanside	5.63			4.02		no data		
City of Carlsbad	10.46			3.22		no data		
City of Encinitas	10.14			1.21		no data		
City of Solana Beach	2.41			0.40		0.47		
City of Del Mar	3.54			0.97		no data		
City of San Diego	32.99			10.62		no data		
City of Coronado	45.06			17.70		1.16 / 3.06		

City of Imperial Beach	5.31			2.41		no data		
Totals	1729.08	7.24 & [14.3]	100.00	188.37	130.37	11.75	30.06	

Key
1. From Boating and Waterways 1977 Report: Assessment and Atlas of Shoreline Erosion along the California Coast
2. From 1971 National Shoreline Study California Regional Inventory, US Army Corp of Engineers
3. From Boating and Waterways 1977 Report: Assessment and Atlas of Shoreline Erosion along the California Coast
4. From the 1989 Series of County and City Interviews completed at U.C. Santa Cruz
5. From 1998 Aerial Oblique Digital Photography Transferred to GIS
6. The 2001 Series of County and City Interviews completed at U.C. Santa Cruz
7. From Both 1971 Nat. Shoreline Study, and Boating and Waterways 1977 Report

BW = Breakwater

SUMMARY OF ERROR ANALYSIS

Santa Barbara Littoral Cell

- ***Erosion Rates*:** Data taken from Griggs, G.B. and Savoy, L.E., 1985. *Living with the California Coast*, Duke University Press, Durham, N.C., 393 p.
- ***Littoral Cut off Diameter*:** (3 Phi/ 0.125mm), 6 beach samples ranging from 98.61%-99.98% > 0.125 mm.
- ***Bedrock/Terrace Heights**:* Twenty-four field measurements were taken over 144 miles of coast using an inclinometer.
- ***Armor Length***: +/- 10%
- ***Percent sand in terrace***: 6 samples; range: 44.6% - 81.1%, average 60%
- ***Percent sand in cliff***: 9 samples: range: -15%- 5.5%; average = 0.1%

SAN DIEGO/OCEANSIDE LITTORAL CELL:

- ***Erosion Rates*:** Data taken from Benumof, B.T. and Griggs, G.B., 1999. The Relationship Between Seacliff Erosion Rates, Cliff Material Properties, and Physical Processes, San Diego, California. *Shore and Beach 67:4: 29-41*.
- ***Littoral Cut off Diameter*:** (3.5 Phi/0.0875 mm): 10 beach samples ranging from 99.39-100% > 0.0875 mm.

- ***Bedrock/Terrace Heights***: Nine field measurements were taken over 48 miles of coast using an inclinometer.
- ***Armor Length:*** +/- 10%
- ***Percent sand in terrace***: 6 samples: range 4.6%-92% average: 59%
- ***Percent sand in cliff*:** 7 samples: range 44.71%-71.3% average: 55.3%

Quantifying the error involved in determining the total volume of sand contributed from the sea cliffs of the Santa Barbara and San Diego littoral cells to the beach and thus the amount of sand prevented from ending up on the beach because of cliff armoring is a challenging problem. The variables and potential sources of error can be significant in a project of this scope, simply because of the length of coast involved in each cell and therefore the amount of shoreline that has to be considered or sampled. The ability to deal with problems of scale was limited by the time available and the budget for the project. The following section discusses the potential sources of error or variance in each component of the sand budget components that were calculated and therefore the confidence in the values determined.

The **height of the bedrock and thickness of the terrace deposits** were determined in the field with an inclinometer. Because nearly all of the bluffs were uplifted coastal marine terraces, the height of the cliffs is quite uniform alongshore and within each study segment. The margin of error in these field measurements was sufficient for the scope of this project and believed to be quite low. Seventy-seven miles of bluffs are involved in the Santa Barbara Cell, and field measurements of bluff height varied from 21 ft to 98 ft. In the Oceanside Cell, 48 miles of shoreline were analyzed and coastal bluffs (comprising 35 miles of this cell) varied in height from 10 ft to 92 ft. Terrace thickness varied from 0.3 to 13.1 ft in the Santa Barbara Cell and from 2 to 20 ft in the Oceanside Cell.

The methods involved in determining the **sand content** for the bluff and terrace deposits have been discussed in this report. In coastal segments ranging from less than a mile to 20 miles long it is difficult to know how representative the sample locations may be in both the Oceanside and Santa Barbara littoral cells. The more samples collected and analyzed, the higher the confidence in the average value obtained. The sand content for the bluffs and terraces were averaged along the entire length of the littoral cells to reduce error, thus a single average value was used for each cell.

A few anomalous samples were encountered during the analysis of the sand content of the bluffs and terraces. In Santa Barbara, one bedrock sample did contain 16% littoral-size material. It was collected from Pt. Santa Barbara, near the Santa Barbara Harbor. This point consists of the Santa Barbara formation, which does contain sand but has only a very limited coastal outcrop area. Also in Santa Barbara, a terrace deposit sample taken from Isla Vista was found to contain only 2.14% sand-size material. This may have resulted from human error when sampling; it is possible that a bedrock sample was interpreted to be a terrace sample. In the Oceanside littoral cell, one bedrock sample contained no sand-size material. This sample was not consistent with the results from the rest of the cell, and was disregarded as anomalous.

The **littoral cutoff diameter** for each cell was determined by means of a sieve analysis. In the Santa Barbara Littoral Cell, six mid-swash zone beach samples were analyzed; 98.6%-99.98% of the sand was coarser than 0.125 mm, thus 0.125 mm (or 3 phi) was taken as the littoral cutoff diameter.

In the Oceanside Littoral Cell, ten beach sand samples were analyzed; 99.4% -100% of the sand in these samples was coarser than 0.088mm (3.5 phi), which was therefore selected as the littoral cutoff diameter. Overall, there was a narrow range of grain sizes in the beach sands in both littoral cells, so the cutoff value used seems to be representative and is not believed to be a significant source of error.

The extent of **armor** throughout the Santa Barbara and Oceanside cells was determined by transferring visually-identified armor from a digital video of the coast to a GIS format using digital 7.5-minute quadrangles as a base map. As previously discussed, armor was often difficult to identify from the video, in part due to the increasing efforts to make new seawalls visually match the existing cliff materials. There also are some low structures that may have been covered with beach sand when the video was shot, thereby making them difficult to recognize. While it is unlikely that a section of unprotected bluff will be mistaken for an armored section, it clear that not all armor could be identified in the video. Thus, we believe that the values obtained for percent of the cells armored represent an underestimate rather than an overestimate. Another challenge in documenting the extent of shoreline armoring was matching the video to the 7.5-minute quadrangles in the GIS. After repeated attempts to digitize the same segment of armor, we determined that there is an inherent digitizing error in this process of ± 50 ft. The digitizing error combined with the visual interpretation error is estimated to be approximately 10% of the total armor.

The greatest potential for error in calculating the sand contribution from sea cliffs is the bluff **erosion rates**. No new erosion rates were calculated in this study. The values used were taken from Griggs and Savoy (1985) for the Santa Barbara Cell, and from Benumof and Griggs (1999) for the Oceanside Cell. Benumof and Griggs (1999) used the most accurate method available for calculating erosion rates to date: soft-copy photogrammetry. The aerial photographs used for the Oceanside Cell span a period of 40-60 years. The average long-term erosion rate was used for this study. *Living with the California Coast* (Griggs and Savoy, 1985) included input on a regional basis from a group of coastal geologists in California, and maps included in that source incorporate the site-specific cliff erosion rates known at that time. These erosion rates were calculated using comparative measurements of historic and recent aerial photographs and maps, although the uncertainty in these data is impossible to quantify. Because most of the Santa Barbara cell shoreline is relatively linear and uniform (two principal formations are exposed), we believe any variations in the measurements were reduced in our use of an average value for the cell segments.

Natural processes vary temporally and spatially. We used the most up-to-date figures available for stream flow and sediment contributions, and collected and analyzed as many samples as time allowed for the calculations of bluff input. While many more samples from the bedrock and terrace deposits of the coastal bluffs would have increased our database, and additional bluff erosion rates would have been desirable, collecting them wasn't feasible in the length of time available for this study. We have used all the reliable data available, and the relatively narrow range in values for erosion rates and littoral sand content, for example, provide confidence that the values obtained are representative. Given the time and scope of this project, a thorough quantitative error analysis was not possible.